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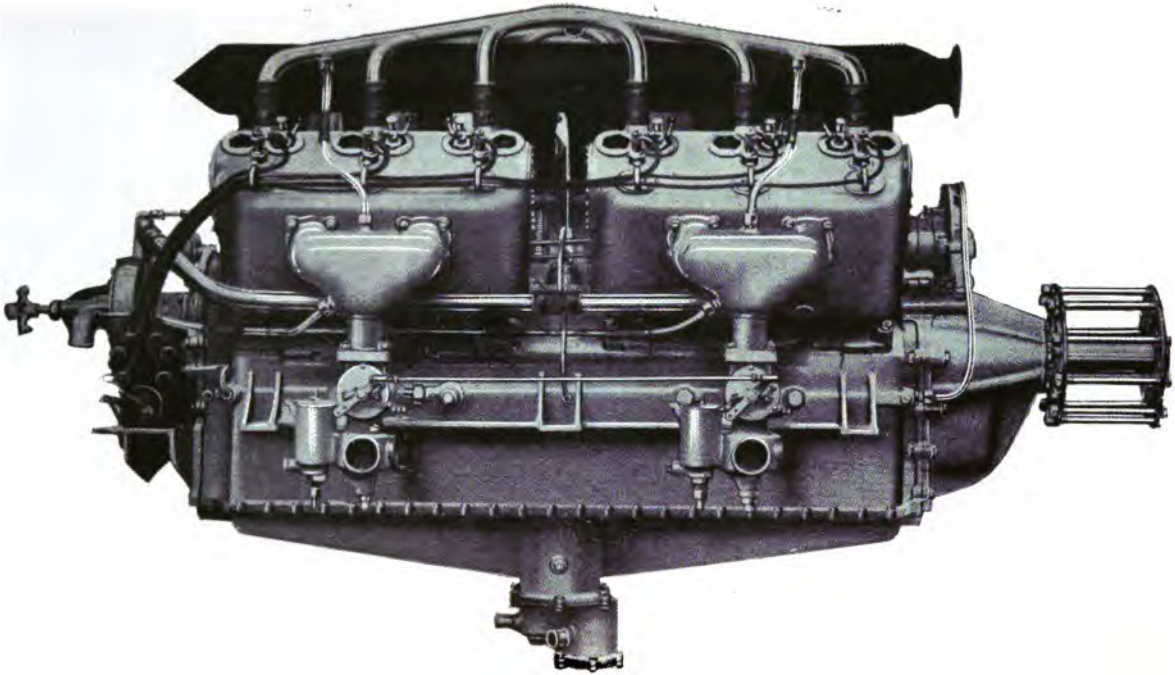

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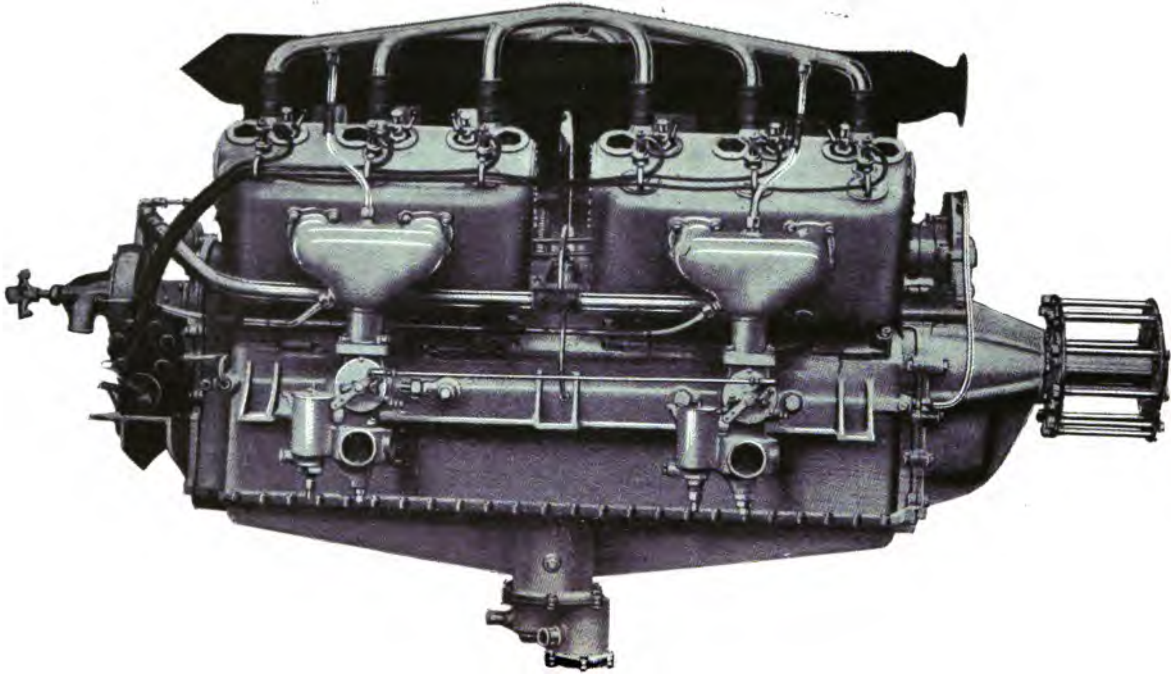

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GAS, OIL,

AND

PETROL ENGINES,

INCLUDING GAS PRODUCING PLANT AND HUMPHREY EXPLOSION PUMPS.

A. GARRARD, WH. EX.

With 112 Illustrations.

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PREFACE.

In the preparation of this book the author has endeavoured to give a clear and reasoned description of the construction and operation of the various types of internal combustion engines. Representative examples have been dealt with, and the illustrations have been carefully selected and prepared.

It is hoped that the subject matter has been presented in such a way as to be clear and instructive to the engineering student or apprentice and to others engaged in engineering works or concerned in the running of internal combustion engines, as well as to other readers interested in the subject.

The author's thanks are due to Messrs. Iliffe & Sons, Ltd., proprietors of "The Automobile Engineer," "The Autocar," etc., and to the various firms mentioned throughout the text for their courtesy in supplying information, some of the illustrations and the material from which other illustrations have been prepared.

1916.

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GAS, OIL, AND PETROL ENGINES.

CHAPTER I.

HISTORY AND DEVELOPMENT.

THE history of the internal combustion engine may be divided into three fairly distinct periods.

(1) From 1678 to 1860, during which time many inventors tried without success to produce a commercially useful gas engine.

(2) From 1860, when the Lenoir gas engine was introduced, to 1878, when the four-stroke cycle engine became the standard.

(3) From 1878 to the present day. During this period the gas engine has been perfected and simplified in construction, and has been made in larger and larger sizes; the liquid fuel engine has been introduced, and such diverse types as the Diesel engine and the motor-car petrol engine have been constructed; and the two-stroke engine has been developed.

The history of gas engines may be said to date from a time when coal gas and petroleum were unknown. This paradoxical statement arises from the fact that the first gas engine proposed by the Abbé de Hautefeuille in 1678 used the explosive force of gunpowder as a motive power. This early gas engine was, however, similar in principle to more modern engines—that is, the work was done by the expansion and cooling of a volume of heated gas, the chief difference being that gunpowder contains the oxygen necessary for its combustion, while gas or liquid fuel requires admixture with the oxygen of the air before they can be made to explode.

Two years after the Abbé de Hautefeuille had published his proposals, the Dutch scientist, Huyghens, published a similar work, describing an apparatus consisting of a cylinder with two leather exhaust pipes forming valves. A small quantity of gunpowder exploded in the cylinder and expelled a large quantity of heated gas through the valves, which closed again when it had passed. The gas remaining in the cylinder soon cooled down, so that the pressure fell below that of the surrounding atmosphere, and caused the piston to be forced down by the excess of atmospheric pressure. This operation was very crude, and did not fulfil the expectations of its inventor.

The idea was, however, not allowed to rest here, and M. Papin set out to find some better agent than gunpowder, the action of which was uncertain and violent. His experiment showed clearly that the condensation of steam was the most suitable means of obtaining in a confined space a pressure lower than that of the atmosphere, and many later inventors adopted this process for working pumping engines; such an engine becomes, however, essentially an *external* combustion engine.

In consequence of the great success of the steam engine, due to Watt and his successors, the possibility of the direct combustion of fuel in the engine was lost sight of for over a century, and it was not till 1791 that any suggestion was made which was an improvement on the engines of De Hautefeuille and Huyghens.

In that year an Englishman, John Barber, described in his patent specification the use of a mixture of a hydrocarbon gas and air, and its explosion in a vessel which he termed an " exploder."

In 1794 Robert Street, also an Englishman, took out a patent for the production of an explosive vapour by means of a liquid and air, ignited by a flame in a suitable cylinder, so as to drive pumping engines and machinery. Petroleum or any other inflammable liquid was allowed to drip on to the heated bottom of a cylinder, and was thus vaporized and forced the piston up.

Philip Lebon, of Brachay, the creator of the coal-gas industry in France, took out a patent in 1799, setting forth the principle and construction of an engine using coal-gas explosively as its motive power. Lebon, in fact, devised his gas-producing plant, with the intention of using the coal-gas in his gas engine, lighting by its means being an after-thought. In a second patent, two years later, he describes an improved apparatus, in which a pump is provided for compressing the mixture of coal-gas and air, and an electric machine, worked by the engine itself, to ignite the compressed mixture. This inventor was assassinated in 1804. If he had lived, it is highly probable that gas engines would have come into general use at the beginning of the nineteenth century instead of nearly 60 years later.

From 1799 until the year 1860, in which the first really practical gas engine made its appearance, several ingenious schemes were put forward, of which the most interesting were due to Welman, Wright, Johnston, and Barnett. In Wright's machine a double-acting cylinder was placed in a vertical position, and the gases were ignited by a gas jet. A centrifugal governor regulated the pumps, which compressed the explosive mixture into the cylinder and at the same time varied the composition of the explosive mixture according to the power required.

About this time a double-acting gas engine was devised by Johnston, using pure hydrogen and oxygen as the explosive mixture, in the proportion of two volumes of hydrogen to one of oxygen. The steam resulting from the combination of the hydrogen and oxygen was expanded, cooled, and finally condensed during the forward movement of the piston, and a partial vacuum thus obtained, which was utilized to assist during the return stroke. This ingenious idea failed owing to the high price of hydrogen and oxygen.

In 1838 William Barnett took out a patent for an engine in which two pumps compressed separately the combustible gas and the air, and forced the mixture under pressure into the cylinder. The explosion was caused by a small gas jet, communication between the jet and the cylinder being set up at the right moment by a revolving valve. The gas jet was situated in the valve itself, and was so arranged that during half-a-revolution it was turned towards the outside, and was then lighted by a second jet, and during the remainder of the revolution it communicated with the interior of the cylinder and ignited the explosive mixture. This was the first gas motor in which ignition was effected from the outside, and in which the explosive gases were at the same time under pressure. In most modern gas engines the result is the same, but the original method of obtaining it has been much modified and improved.

During the next few years several patents relating the same subject were taken out. In 1844 John Reynolds proposed that ignition should be effected by a ring of platinum wire raised to a white heat, by the current from an electric battery, the ignition taking place at the required moment by closing a switch in the battery circuit. In 1850 Stéphard recommended, instead of the primary battery. a magneto-electric machine driven by the engine itself.

Barsanti and Matteucci described, in 1857, an atmospheric motor, their arrangement of the parts being afterwards adopted by Otto and Langen. A Bunsen cell supplied current to a De La Rive multiplier, causing a stream of sparks to pass between two fine points situated within the combustible mixture.

In 1858 and 1859 Degrand described in two patents a gas engine in which the gases were compressed in the cylinder itself. Owing to mechanical difficulties his machine was impracticable, but the suggestion marks an important step in the history of gas engines.

In 1860, when the Lenoir motor appeared, no other engine capable of regular and comparatively efficient work was in existence. The Lenoir engine had the appearance of a double-acting horizontal steam engine. There was no compression of the explosive mixture before ignition, which was effected by an electric spark produced by a Ruhmkorff coil and a primary battery. The machine ran smoothly and regularly and its cost was moderate. It possessed the advantage of the absence of a cumbrous boiler and costly foundations; and little care and attention were necessary to keep it in working order. Although the fuel consumption was very high, many hundreds of engines were made and delivered, and some of them continued in use for a number of years.

The success of the Lenoir engine served to redirect the attention of inventors and engineers to the problem of the production of a commercially useful gas engine.

Among the numerous patents taken out in consequence of this activity, the most important, filed in 1860 by M. Hugon, related to a gas motor with flame ignition, the cylinder being cooled by injecting into it a very fine spray of cold water. Experiments were made upon it in 1876 by M. Tresca, and it was found that the motor consumed 2,445 litres of gas per horsepower hour. The temperature of the exhaust gases was 180° C., while in the Lenoir motor it was about 280° C. This diminution of temperature was probably due to the better method of cooling the cylinder, and was found to be a great improvement, the cylinder requiring much less lubrication.

In 1861 Kinder and Kinsey somewhat modified the existing arrangement of the parts, but otherwise their motor embodied no new ideas.

The year 1862 was memorable in the history of the gas engine, for in that year M. Beau de Rochas took out a patent in which he discussed at length the best working conditions for a gas engine. He, in common with others, recognised the advantage of compressing the mixture before ignition takes place, and further suggested a means of effecting the compression without using a separate pump. The explosive mixture was to be drawn into the cylinder during the forward stroke of the piston and compressed during the return stroke; the explosion was to take place at the beginning of the second forward stroke and drive the piston forward, the gases being expelled during the second return stroke. The whole principle will be seen to consist of four distinct operations, forming what is known as the Otto, or four-stroke cycle, for reasons which will presently be explained. The peculiar part of the patent was its purely theoretical character. Whilst giving all the honour due to the inventor, and recognizing that he fully understood his subject, we must not forget that there was nothing whatever in the patent indicating how the ideas embodied therein might be carried into practice. No drawings were appended to the text; it contained nothing, in fact, but a plain statement of the most efficient cycle of operations. M. de Rochas did not construct a machine on this principle, and, as he omitted to pay his patent renewal fees, the idea became public property. No attention was drawn to it until ten years later, when it came to light during some patent litigation undertaken by Dr. Otto in 1878.

In 1867, at the International Exhibition held at Paris, a vertical atmospheric motor, based on the primitive principle of the gunpowder pump of De Hautefeuille, was shown working. This machine was constructed by two German engineers, Otto and Langen, and was a perfected form of the Barsanti and Matteucci motor invented ten years before. The explosion of the gases in the cylinder served to obtain a partial vacuum underneath the piston, which was, therefore, forced down by the excess of atmospheric pressure above it. This motor was much more economical than the Lenoir and Hugon motors, and consequently it came rapidly into favour, and the inventors were able to sell several thousands in a few years.

The motor itself was very rough and noisy, but, as the later designs constructed in 1872 only consumed 800 litres of gas per horse-power hour, rendering power produced by this means cheaper than steam, the success of the motor was assured in spite of its defects.

The success of these early attempts stimulated Dr. Otto to further efforts, and in 1878 he brought out his famous gas engine, which has earned a world-wide reputation. It was based on the principle of the De Rochas patent, of which we have spoken above, but Otto undoubtedly knew nothing of this patent. The enormous success which the new motor rapidly attained led to many imitations, and legal proceedings were instituted in England and France. In this country the validity of Otto's patents were upheld, but in France the De Rochas patent was for the first time brought to light, and the verdict went against Dr. Otto. This verdict has been attributed to bias on the part of the French judges, owing to the strong national feeling against the Germans; but in any case we are indebted to Dr. Otto for having made the gas motor a really practical engine after many years of patient experiment and study. This engine has been called the Otto silent engine, to distinguish it from its noisy predecessor, the engine of Otto and Langen.

Three other engines appeared about the same time, designed respectively by Bisschop, Simon, and Ravel. The Simon motor, of which only a very small number were constructed, was very interesting from the point of view of economy. The explosion of the mixed gas was not allowed to take place suddenly, but proceeded gradually as the piston moved forward, and the heat, which in the Otto engine is carried off by the water-jacket, was made use of as in the old Hugon motor, to vaporize a spray of cold water, thus adding to the total force behind the piston. This process was so effective that the pressure due to the vaporization of the water was sufficient to keep the motor in motion for a considerable period after the supply of gas was shut off. About 800 litres of gas and 4 litres of water per horse-power hour were consumed, this being then a very good result. The Ravel motor consumed even less, but the mechanical efficiency was very low.

The Otto gas engine was the first to come widely into use, and, when Otto's master patent expired, nearly all other gas engines followed on the same lines. Messrs. Crossley first manufactured it in England, and it was soon extensively used.

For many years coal-gas was the only fuel available, and the engine was used for small powers only owing to the cost of the fuel. Engines of more than 20 horse-power were rarely made.

In 1881 Mr. J. Emerson Dowson applied a cheap form of gaseous fuel produced by a special process in a producer to the driving of a gas engine, and gas engines then increased rapidly in size. At the present day nearly every gas engine maker supplies gas producing plant for use with his engines. Producer gas plant on a very large scale has been introduced since then, notably by Mond. In 1895 Mr. B. H. Thwaite showed how the so-called waste gases from blast furnaces could be applied to the driving of gas engines.

The possibility of using cheap gas has given a great impetus to the construction of large gas engines, and they are now built to develop many hundreds and even thousands of horse-power.

Many modifications of the Otto gas engine have appeared since 1878, one of the principal forms being a two-stroke engine devised by Mr. Dugald Clerk in 1881. His engine required a pump, and it was thus less simple in this respect than the Otto engine, in which the working cylinder itself serves as a pump. The Clerk cycle met with some success as long as the Otto patents were in force, but it fell into and remained in disuse as long as small gas engines only were produced. The later developments of large gas and oil engines resulted in the re-introduction of the Clerk cycle, and it is now extensively used where large powers are required.

In the ordinary Otto cycle, the clearance space contains exhaust products at the end of the exhaust stroke, and these products mix with the incoming charge. To avoid this, Griffin introduced, in 1883, a gas engine having two additional scavenging strokes. The Griffin engine may be said to work on a six-stroke cycle. There was, however, not sufficient advantage to compensate for the complications resulting from the two additional idle strokes, and this idea was soon given up.

In 1885 Mr. Atkinson introduced a very ingenious "differential" engine, in which the explosion and other operations took place in the space between two pistons in the same cylinder, the pistons being adapted to approach to and recede from one another.

The suction stroke was short and the working stroke much longer, thus giving a large ratio of expansion to the burning gases. Moreover, the exhaust gases were almost completely expelled by the two pistons coming close to one another at the end of the exhaust stroke. Some years later Mr. Atkinson abandoned this construction, and introduced an engine having a single piston, which was given long and short strokes alternately. The first oscillation served to draw in and compress the mixture, while the second, which was about twice as great, served for the working and exhaust strokes. This engine had, what was at that date, a very high thermal efficiency, but the necessary mechanism was too complicated for it to become commercially successful. Both of these engines are now obsolete.

The Brayton gas engine was constructed in America in 1873, but was not sufficiently economical to enable it to compete with the engines of Otto and Langen. The engine worked well and smoothly, however, but the flame ignition was the weak point. There was a considerable risk of the flame going back into the reservoir and exploding all the mixture. This led Mr. Brayton to convert his engine into a petroleum engine.

The small high-speed engine consuming light oil, now known as petrol, was originated by Daimler, a German, in 1883. These little engines have ultimately developed into such great power producers in proportion to their weight that they have, in a few years, completely revolutionized road locomotion in nearly all countries, and have assisted largely in making mechanical flight commonplace.

Daimler ran the first motor-propelled car in 1887, and in 1889 Messrs. Panhard and Levassor started to manufacture motor cars in France.

The Otto cycle has further been applied in the development of engines using heavier oil, such as ordinary paraffin or lamp oil. Priestman, an Englishman, introduced the first practical oil engine about 1885, and it was soon applied for many purposes on land and water. The Hornsby-Ackroyd engine, invented by Mr. H. Stuart Ackroyd, was introduced about 1890, and has been used in very large numbers. This was the first engine which was successful in utilizing the hot walls of the combustion chamber to vaporize and ignite the fuel.

A very important development of the heavy oil engine was introduced by Dr. Diesel, a German, about 1895. In the Diesel engine pure air alone is compressed to such a high pressure that its temperature is raised above the ignition point of the oil fuel. The fuel is then injected by means of highly compressed air. The Diesel engine is constructed to work on both the four- and the two-stroke cycles, and it is now used very extensively, both for land and marine work, generally for high powers.

The so-called semi-Diesel or hot-bulb engine is an interesting type, partaking of the characteristics of the Diesel engine and of the earlier oil engines. In this engine, as in the Diesel engine, pure air is compressed, and the fuel is injected at the end of the compression stroke, but the compression is less than in the Diesel engine, and ignition is effected by the combined heat of the combustion chamber and of compression. This type of engine works on either the four- or the two-stroke cycle.

This principle was first suggested in 1890 in a patent taken out by Messrs. H. Ackroyd Stuart and C. R. Binney. Nothing further appears, however, to have been done in this direction until after the introduction of the Diesel engine. The semi-Diesel engine appears to have developed from, and to have been regarded generally as, a modification of the Diesel engine.

One of the latest developments is the internal combustion pump, first successfully applied by Mr. H. A. Humphrey in 1909. This pump is constructed to work on either the four- or two-stroke principle, and deals with very large quantities of water. The piston is replaced by an oscillating column of water. Producer gas is used as fuel.

A novel method of cooling large gas engines by the injection of water has been proposed by Professor Hopkinson, and has been found to operate very well. There is no water-jacket, but water is injected into the compression space during the compression stroke, and sprays against the heated metal surfaces, from which it removes heat directly by evaporation.

This brief review of the history and development of the internal combustion engines shows that very great progress has been made since 1878, when the four-stroke compression engine became the standard. There are, however, still many directions in which improvement is possible. The internal combustion engine is still dependent upon the use of a cylinder and piston, in which respect it is inferior to the steam turbine. The gas turbine has not yet arrived, although much research and experiment have been undertaken with the object of overcoming the practical difficulties resulting from the very high temperatures of the working fluid.

CHAPTER II.

GENERAL PRINCIPLES.

Heat, Work, and Efficiency.—It is probable that the whole of the energy at our command for commercial purposes was originally received from the sun in the form of heat; this heat has been stored up under certain circumstances in a latent form in chemical compounds, such as coal, petroleum, wood, etc. The steam engine and the internal combustion engine enable some portion of this potential energy to be converted into heat energy and further transformed into mechanical work; and, in order to realise how this may be done to the greatest advantage, it is necessary to consider the laws of heat and heat engines.

The experiments of Joule first showed that energy could be converted from one form to another in certain definite proportions, but was never lost or destroyed. This is called the principle of the conservation of energy and the relation between energy in the form of heat, and that in the form of work forms the first law of thermo-dynamics, which is enunciated as follows :—Whenever work is done, the energy expended in doing the work is exactly proportional to the heat produced and *vice versâ.* The numerical relation between heat and work is referred to as the mechanical equivalent of heat or Joule's equivalent. It has been found by experiment that the mechanical equivalent has the value 778 if the British thermal unit (B.Th.U.) is taken as the unit of heat and the foot-pound as the unit of work—that is to say, the heat necessary to raise the temperature of 1 lb. of water one Fahrenheit degree is equivalent to the work done in raising a weight of 778 lbs. through a distance of one foot. The mechanical equivalent has the value 1,400 if the temperature is measured on the Centigrade scale. If the units employed are the calorie or kilogramme Centigrade unit, and the kilogramme metre, the value of the mechanical equivalent is 424; or, expressed otherwise: —The heat necessary to raise the temperature of one kilogramme of water 1 Centigrade degree is equivalent to the work done in lifting 424 kilogrammes vertically through a distance of one metre.

The steam engine and the internal combustion engine are both classed as heat engines—that is, engines by means of which the heat energy of the fuel is converted into mechanical work. In all heat engines some fluid, such as steam, air, gas, or vapour, is employed as a medium for the conversion of the heat energy into mechanical work. Only a small part, however, of the heat energy is so utilised, the greater part being rejected. In the most efficient internal combustion engines—the Diesel engine, for instance—only about 35 per cent. of the heat is utilized, the remaining 65 per cent. being wasted, most of it going off in the cooling water and the exhaust gases. Generally the wastage is much greater. As an example, many thoroughly efficient hot-bulb or similar oil engines burn ·6 lb. of petroleum per horse-power-hour. The amount of heat given to the engine is ·6 × 18,000 = 10,800 B.Th.U., and the amount utilized (that is, the heat equivalent of a horse-power-hour) is only 2,540 B.Th.U.

The efficiency of this engine is equal to

$$\frac{\text{Useful work done (expressed in heat units)}}{\text{Energy originally supplied (also in same heat units)}}$$

$$= \frac{2{,}540}{10{,}800} = \cdot 235, \text{ or } 23\cdot 5 \text{ per cent.}$$

23·5 per cent. of the energy supplied is thus utilized, the remaining 76·5 per cent. being wasted.

The working fluid of heat engines receives heat from the fuel at a relatively high temperature, and rejects a large proportion of this heat at a lower temperature, the difference between these two quantities being the amount utilized in doing mechanical work.

The relation between the heat received and the heat rejected depends upon the temperature at which the heat is supplied and that at which it is rejected. In an internal combustion engine the efficiency depends upon T_1, the temperature of explosion or combustion, and T_2, the temperature of the exhaust gases, the efficiency being equal to

$$\frac{\text{Heat equivalent of work done}}{\text{Heat supplied}} = \frac{W}{H}.$$

The ideal or highest possible efficiency is equal to—

$$\frac{W}{H} = \frac{T_1 - T_2}{T_1}.$$

T_1 and T_2 are expressed in absolute units of temperature, and not in the ordinary temperature scales, the absolute zero of temperature being that temperature at which the molecules of any substance are supposed to have no motion. Various considerations point to the absolute zero of temperature as being 273° below 0° C. (the freezing point of water), or as having the value $-273°$ C., although such a low temperature has never been actually obtained.

Fig. 1 shows diagrammatically an air thermometer in which a piston A of mercury confines a quantity of air in a tube having its lower end closed. As the temperature varies the piston moves up or down according to the expansion or contraction of the air.

The Centigrade scale on the left and the absolute scale on the right show the relation between the two. A temperature of 70° C., for instance, would be 273 + 70 = 343° when expressed in absolute units.

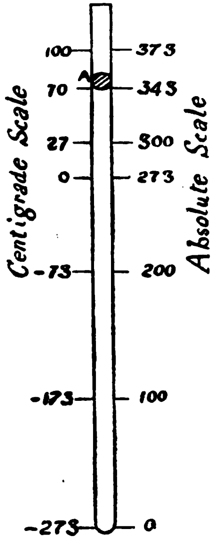


Fig. 1.
Temperature Scales.

If an engine is to be perfectly efficient—that is, to reject or waste none of the heat supplied to it—W must be equal to H, or,

$$\frac{W}{H} = 1 = \frac{T_1 - T_2}{T_1}.$$

In this case T_2 must have the value zero—that is, the temperature of the exhaust gases must be equal to the absolute zero of temperature. Since this is an impossible condition, it follows that what may be called the practical ideal heat engine can only have an efficiency which is very much less than unity.

As an example, suppose the highest temperature of combustion in a gas engine is 2,000° C., and the temperature of the exhaust gases is 1,000° C., the efficiency of the engine would be

$$\frac{T_1 - T_2}{T_1} = \frac{2{,}273 - 1{,}273}{2{,}273}$$

$$= \frac{1{,}000}{2{,}273}$$

$$= \cdot 44 \text{ or } 44 \text{ per cent.}$$

The actual efficiency of the engine would be considerably less than this theoretical efficiency; for example, 25 per cent. would be quite a good practical efficiency for many engines.

From the above considerations, it will be seen that in the main the highest efficiencies are obtained by making the range of temperature as great as possible.

The difficulty of lubricating the cylinder tends to limit the initial temperature, iron at 400° C. being red hot and decomposing any lubricant coming in contact with it.

The highest possible efficiencies of heat engines working on this principle of the reception and rejection of heat are necessarily very much less than unity, and until some new principle of operation is discovered, we shall have to be content with throwing away two-thirds or thereabouts of the heat of the fuel.

Cooling Cylinders.—The temperatures referred to above are the temperatures of the burning gases in the cylinder; the temperature of the cylinder walls is kept very much lower, generally by means of a water-jacket, through which cooling water is kept continually flowing. This has two results:—

(1) The cylinder walls are kept cool enough to allow lubricating oil to remain on them without being burnt, and thus allow the piston to move to and fro freely without much friction; and

(2) It is possible to draw a full charge of combustible mixture into the cylinder. If the cylinder walls were kept at an excessively high temperature, the mixture as it entered would be heated and would, in consequence, expand. Although the same volume would be drawn into the cylinder, the mass or weight or quantity would be less; the force of the explosion would also be less and the result would be a loss of power. This is a well-known consequence of an overheated cylinder.

The Four-stroke Cycle.—The majority of the internal combustion engines of to-day work on what is generally known as the Otto, or four-stroke, cycle of operations, in which there is only one working stroke in every four strokes or two revolutions; the remaining three strokes being merely preparatory strokes for the fourth effective stroke.

The cycle of operations of a single-acting four-cycle gas engine is illustrated diagrammatically in figs. 2 to 5, and is as follows :—

(1) *Suction Stroke.*—The inlet valve I is open, and the movement of the piston draws in a mixture of air and gas or combustible vapour.

(2) *Compression Stroke.*—Both valves are closed, and the mixture is compressed into the clearance space by the return movement of the piston, the pressure and temperature both rising considerably.

(3) *Working Stroke.*— Both valves still remain closed; when the mixture is fully compressed, it is ignited by an electric spark or hot tube or other means, and burns very rapidly or explodes; this forces the piston forward and rotates the crank-shaft.

(4) *Exhaust Stroke.*—The exhaust valve E is open, and the return movement of the piston expels the products of combustion.

In these diagrams the mixture in the cylinder before combustion is indicated by straight lines and the products of combustion by dots.

This cycle of operations thus takes two revolutions for its completion. Each valve is raised every alternate revolution, and is, therefore, operated, generally by cams, from a half-time shaft, which is geared to, and rotates at, half the speed of the crank-shaft.

It is necessary, when starting, for the engine to be turned by hand or by some external source of power, to enable the suction and compression strokes to be

The Four-Stroke Cycle.

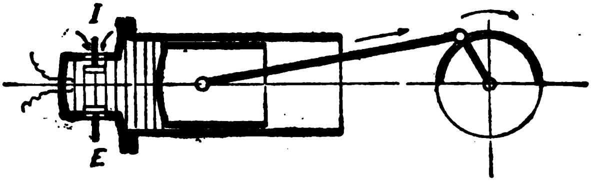


Fig. 2.—Suction Stroke.

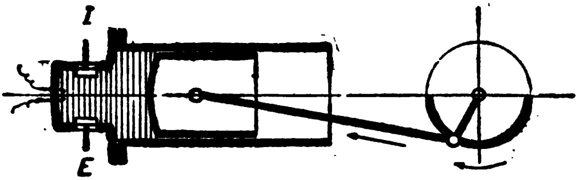


Fig. 3.—Compression Stroke.

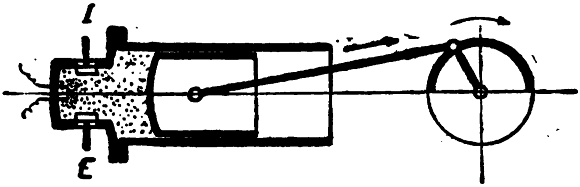


Fig. 4.—Working Stroke.

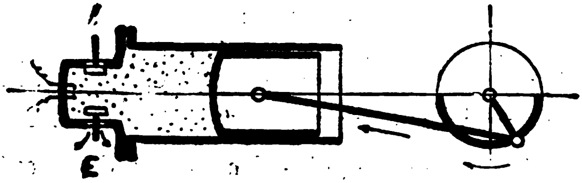


Fig. 5.—Exhaust Stroke.

made as a preparation for the first working stroke, after which the engine will continue to run. When running, a heavy flywheel stores up energy during the working stroke, and keeps the engine going during the exhaust, suction, and compression strokes.

In the foregoing description of the Otto cycle a single-acting engine has been considered—that is, an engine in which the explosion or combustion takes place on one side only of the piston, the other side being subject to atmospheric pressure. The single-acting principle is very extensively adopted, in view of its simplicity and cheapness. In a double-acting engine provision would have to be made for pressure acting on both sides of the cylinder. This would necessitate the closing of the inner end of the cylinder. The piston would then no longer serve as the crosshead; a separate crosshead would be required. A piston rod, cylinder cover, and stuffing-box would also be required, and the overall length of the engine would be greater. The valves and valve-operating gear would also have to be duplicated. The cooling of the piston would also be rendered more difficult. As a set-off to the above disadvantages, the power developed in a double-acting engine is nearly double that developed in a single-acting engine of the same size.

For engines of small and medium size up to, say, 120 H.P. per cylinder, the single-acting principle is almost universally adopted; when higher powers are required on the Otto cycle without corresponding increase of size and weight, the double-acting principle is sometimes preferred. The various ways in which more power per cylinder is obtained will be described in subsequent chapters.

The Two-stroke Cycle.—The great disadvantage of the Otto cycle is the fact that three out of every four strokes are ineffective; one of them, the compression stroke, even having a very great retarding effect. This has two principal results. Firstly, a very heavy flywheel is necessary to prevent the rotation of the crank-shaft from being irregular or jerky. Secondly, the engine must be very much larger than an engine developing the same power, but making fewer ineffective strokes.

Many attempts have been made to lessen these disadvantages, and one result has been the two-stroke cycle engine, in which every other stroke is a working stroke—that is, an impulse is obtained once every revolution.

Starting with the working stroke, the piston moves forward, and when near the end of its stroke uncovers an exhaust port, through which the exhaust gases escape. An inlet port for the explosive mixture is uncovered a little later, and a fresh charge is forced in under pressure. The piston now returns, covers both the exhaust and the inlet ports, and compresses the mixture. When the piston reaches the end of this stroke, and compression is complete, the mixture is ignited and a new working stroke commences. The cycle of operation is thus completed in one revolution instead of two, as in the other cycle.

The mixture is compressed before it enters the cylinder, in order that it may enter rapidly, since the time available for it to enter is very short, the inlet port being uncovered for only a small fraction of the stroke. This compression is obtained in various ways; the different methods will be described later in connection with the different kinds or makes of engine working on the two-stroke cycle.

One disadvantage of the two-stroke cycle is the unavoidable mixing of the incoming explosive mixture with a residue of the exhaust gases, resulting in a loss of efficiency. A further disadvantage is the possibility of some of the incoming mixture from the cylinder passing out with the exhaust before the exhaust port is covered by the piston. In the case of engines working with crank-case compression (to be described later), there is always the possibility of some of the charge leaking through the crank case joints and bearings, and of an excessive quantity of lubricating oil being carried by the charge from the crank case to the cylinder, increasing the risk of the sparking plugs, when these are employed, becoming sooted.

A still further disadvantage, of great importance in motor-car engines is the want of flexibility of two-stroke engines—that is to say, good running is only obtainable within quite narrow limits of speed.

Both the four- and the two-stroke cycles are modified to some slight extent in different engines. These modifications will be dealt with in subsequent chapters.

The several operations taking place in a two-stroke vertical engine with crank-case compression are shown diagrammatically in figs. 6 to 9.

Exhaust Period.—This commences by the uncovering of the exhaust ports E just before the end of the down or working stroke, and finishes at the same point on the up stroke.

Inlet Period.—This commences by the uncovering of the inlet or transfer port I a little later than the opening to exhaust. The explosive mixture, which has been previously compressed in the crank case by the downward movement of the piston, now rushes through the passage I to the cylinder, and tends to displace the residue of the exhaust gases. The shape of the top of the piston is such that the incoming mixture is directed upwards, so that it tends to sweep out the exhaust gases before it instead of escaping directly through the exhaust ports. The inlet period commences after and finishes before the exhaust period.

Compression Stroke.—The explosive mixture is now

The Two-Stroke Cycle.

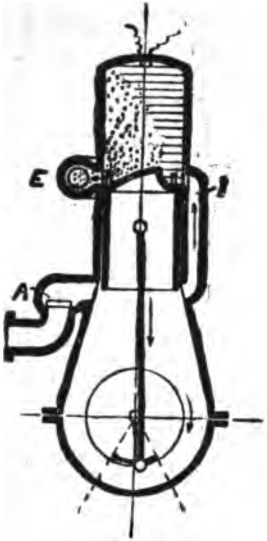


Fig. 6.—Exhaust Period.

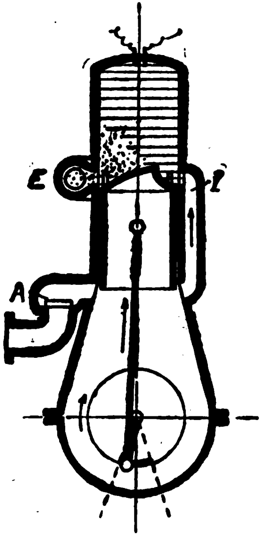


Fig. 7.—Inlet Period.

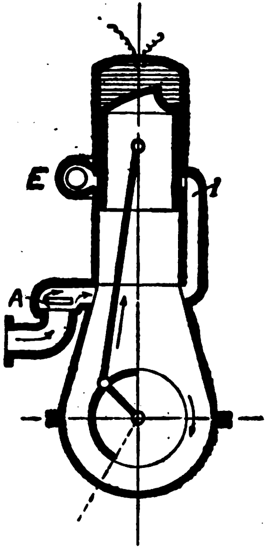


Fig. 8.—Compression Stroke.

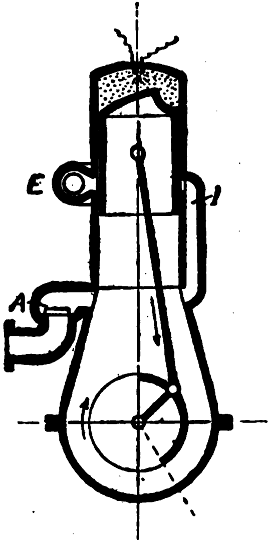


Fig. 9.—Working Stroke.

compressed in the cylinder by the upward movement of the piston, and, at the same time, a fresh supply of mixture for the succeeding cycle of operation is drawn into the crank case through the non-return valve A.

Working Stroke.—At or slightly before the upper dead centre, the mixture is ignited and the piston is forced downwards. The mixture drawn into the crank case on the previous up-stroke is compressed at the same time. Towards the end of this stroke the exhaust port is uncovered by the piston, and the cycle is repeated.

Clearance.—The internal combustion engine differs from the steam engine in that provision must be made for a definite and relatively large amount of clearance, the clearance being the volume of the combustion chamber or the space left at the end of the cylinder when the piston is at the inner end of its stroke. The amount of the clearance determines the pressure at the end of the compression stroke, which may vary greatly according to the type of engine. Some low-compression petrol, gas, or oil engines compress the mixture to a pressure of from 45 to 50 lbs. per square inch. In such a case the clearance volume would be about one-third of the volume of mixture entering the cylinder in each stroke. As an extreme instance of a high-compression engine, the compression pressure in the Diesel engine is from 400 to 500 lbs. per square inch, this high pressure being obtained by reducing the clearance volume so that it is about one-tenth of the cylinder volume; the charge of air is compressed by the movement of the piston into a smaller volume than in the first-mentioned case.

Indicator Diagrams.—The variation of pressure in the cylinder can be shown very clearly by an indicator diagram (see fig. 10), in which the volume of

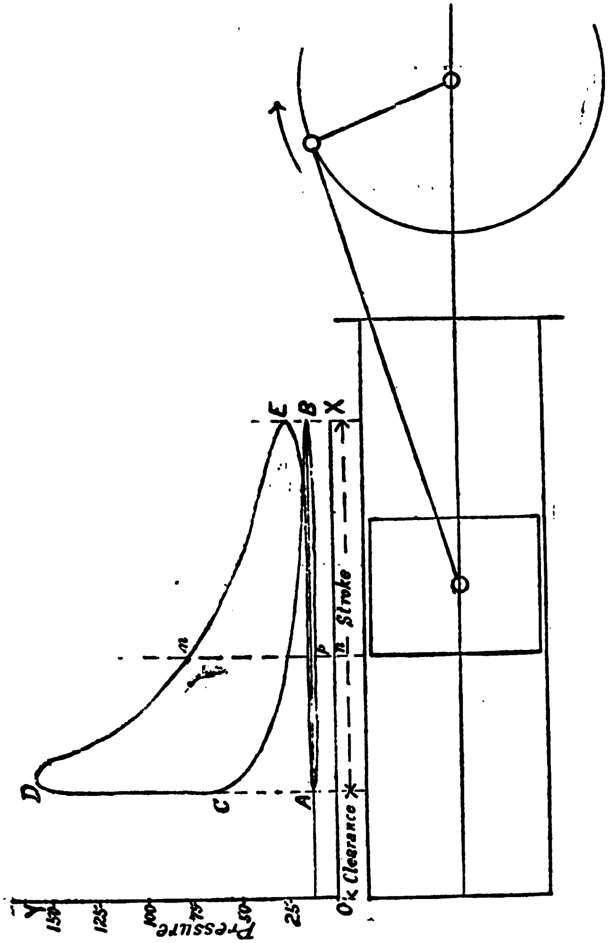


Fig. 10.—Indicator Diagram.

the working substance in the cylinder or the stroke of the piston is measured horizontally parallel to

O X, and the pressure in the cylinder is measured vertically parallel to O Y. In this diagram, which refers to an engine working on the Otto cycle—

A B represents the suction stroke, the pressure being practically equal to that of the atmosphere, or about 14·7 lbs. per square inch.
B C shows how the pressure rises as the piston returns and compresses the mixture.
C D shows the sudden rise of pressure due to the ignition and combustion of the mixture.
D E represents the working stroke, in which the hot gases expand and force the piston forward while their pressure and also their temperature decrease.
E A represents the exhaust stroke during which the waste gases are expelled from the cylinder by the return of the piston.

When the piston is in the particular position shown, the pressure on the working stroke is represented by the length *m n*, in this case 75 lbs. per square inch. The pressure with the piston in the corresponding position on the suction stroke is given by the length *n p*, and is slightly less than 14·7 lbs. per square inch.

The highest pressure reached on the compression stroke is represented by the length A C (about 65 lbs. per square inch) in the diagram. The compression varies in different types of engines, being highest in those engines in which pure air only is compressed. It is necessarily limited, in engines in which an explosive mixture is compressed, to prevent premature ignition due to the rise of temperature which accompanies the compression. The compression pressures for a few types of engines are as follows :—

Gas engines using producer gas—up to 130 lbs. per square inch.

Gas engines using town gas—up to about 110 lbs. per square inch.
Ordinary oil or petrol engines—about 80 lbs. per square inch.
Hot-bulb injection engines—up to about 350 lbs. per square inch.
Diesel engines—450 to 500 lbs. per square inch.

Power.—Frequent reference will be made to the power developed by engines. Briefly, power is simply the rate of doing work. The unit of power adopted in this country is the horse-power (H.P.). This means that an engine developing 1 horse-power is capable of doing work at the rate of 33,000 foot-lbs. per minute. For instance, it may be capable of lifting 1,000 lbs. through a distance of 33 feet in one minute, or of exerting a pull of 11 lbs. on a rope, and of winding it in at the rate of 3,000 feet per minute. In each of these cases the product of force and distance per minute gives the work done per minute, and if the work per minute be divided by 33,000 the power developed by the engine is obtained. Consider, as a further numerical instance, a winding engine which is capable of hauling in a rope at the rate of 1,000 feet per minute with a pull of 330 lbs. The work per minute done by this engine

$$= 330 \times 1{,}000 = 330{,}000 \text{ foot-lbs.}$$

$$\text{The horse-power} = \frac{330{,}000}{33{,}000}$$
$$= 10.$$

When an engine is tested with the object of determining the power which it will give, the work done by it per minute is measured by a device called a dynamometer, for absorbing or transmitting the energy. A brake arranged on the flywheel is a form of dynamometer very commonly employed, and the horse-power obtained in this way is, therefore, called the brake horse-power (B.H.P.).

The horse-power may also be calculated by measurement of the area of the indicator diagram, the speed, and certain engine dimensions. The horse-power calculated in this way gives the indicated horse-power (I.H.P.). The I.H.P. is always rather larger than the B.H.P., owing to frictional losses of energy in the working parts.

The term " horse-power-hour " is given to the total amount of work done in one hour by an engine which continuously develops 1 H.P. It is equal to

$$33{,}000 \times 60 \text{ foot-lbs.}$$

CHAPTER III.

FUEL AND COMBUSTION.

INTERNAL combustion engines may be divided into three main classes, according to the kind of fuel employed.

1. The gas engine burning coal gas, blast-furnace gas, or fuel gas, such as Mond gas or Dowson gas, the last-named being obtained by special processes to be described in Chapter IX.
2. The petrol engine in which liquid hydrocarbons volatile at ordinary temperatures are employed.
3. The heavy oil engine which utilizes kerosine, crude oil, or other heavy fuel oil.

All the above fuels are almost exclusively composed of hydrogen and a number of chemical compounds of carbon and hydrogen in various proportions. The physical and thermal characteristics of any particular fuel depend upon the qualities and proportions of the compounds of which it is composed. The properties of any particular compound depend upon the relative quantities of carbon and hydrogen which it may contain. For instance, coal gas consists largely of hydrogen and methane, the latter being composed of one atom of carbon in chemical combination with four atoms of hydrogen. The composition of methane is commonly shown by the symbol CH_4.

Combustion.—When considering the quantity of heat obtainable by the combustion of fuel or the weight of air required for such combustion, it is sufficient to look upon any fuel as consisting of carbon and hydrogen in certain proportions. The combustion, whether it takes place in the cylinders of an internal combustion engine or anywhere else, may be regarded solely as a chemical action in which both carbon and hydrogen combine with oxygen obtained from the air, with the consequence that a great quantity of heat is generated; this heat expands the products of combustion momentarily to many times their original volume; if the expansion is restricted there is instead a great rise of pressure, or there may be an increase both in volume and pressure. Take petrol as an example. If 2½ volumes of petrol vapour mixed with 97½ volumes of air be introduced into a strong closed vessel and the mixture ignited by an electric spark, the pressure on the walls of the vessel may be as high as 200 lbs. per square inch, the products of combustion being at a very high temperature. As soon as the contents of the vessel have cooled down to their previous temperature, it will be found that the pressure is not greatly different from the pressure of the combustible mixture originally introduced, thus showing that the pressure of the explosion (as it is called) is a temporary effect due to the sudden heating of the contents of the vessel, and is not due to a permanent increase of volume or pressure. This action is similar to that taking place in the cylinder of an internal combustion engine, with this difference that the pressure of the explosion drops very quickly as the piston is forced forward and the volume increases.

The relation between the quantity of fuel to be burned and the quantity of air required to bring about complete combustion will now be considered. If carbon is burned completely 1 atom of carbon combines with 2 atoms of oxygen, and forms the compound carbon dioxide popularly known as carbonic acid gas, this chemical action being accompanied by the generation of a great deal of heat. Similarly, when 2 atoms of hydrogen combine with 1 atom of oxygen, the resulting compound is steam, which is, at the high temperature at which the combustion takes place, a perfectly invisible gas.

Atmospheric air consists of two invisible gases, oxygen and nitrogen, in the proportion by weight of 23 parts of oxygen to 77 parts of nitrogen. These gases are not chemically connected in any way, but are merely mixed together. The oxygen is the active element in combustion, the nitrogen being quite inert, and merely serving to dilute the combustible mixture or the products of combustion.

For the complete combustion of 1 lb. of carbon it is necessary to supply 11·6 lbs. of air, and similarly, 1 lb. of hydrogen requires 34·8 lbs. of air. These quantities are the very least that will burn all the fuel, and in practice it is generally advisable to supply an excess of air, with the object of preventing any of the carbon or hydrogen particles passing out with the exhaust gases without having had an opportunity of combining with the particles of oxygen. Each atom of carbon or hydrogen must come into sufficiently close contact with the proper number of atoms of oxygen for the chemical combination with the resultant generation of heat to be effected. This necessitates a very complete and intimate mixing of the particles of the fuel with the particles of air. If the mixing action is not sufficient, then free carbon, hydrogen, and oxygen atoms may pass away with the exhaust gases without ever approaching one another sufficiently for them to combine. Such loss of carbon and hydrogen means that some of the heat energy of the fuel is being wasted.

In the case of a liquid fuel it is necessary to spray or atomize the fuel very completely to prevent the heat of the burning portion from distilling and decomposing the unconsumed parts of the liquid with formation of heavy smoke. Efficient spraying reduces the size of the drops of liquid fuel to such an extent that oxygen is able to contact with each particle of the oil mist and ensure its being burnt completely.

When 1 lb. of hydrogen is burned completely, the total quantity of heat generated by the combustion is 62,000 B.Th.U., or pound-Fahrenheit units, which were defined in the previous chapter. The combustion of 1 lb. of carbon results in the generation of 14,600 B.Th.U.

These chemical actions may be represented by the chemical equation—

$$\begin{aligned} C + 2O &= CO_2 + 14{,}600 \text{ B.Th.U.} \\ 2H + O &= H_2O + 62{,}000 \text{ B.Th.U.} \end{aligned}$$

The calorific value of 1 lb. of fuel—*i.e.*, the heat generated by its combustion—depends upon the relative proportions of hydrogen and carbon which it contains.

The following shows the calorific value in British thermal units of 1 lb. of the following fuels :—

Benzol, as usually supplied for motor spirit, ...	17,780
Peat, with 18 per cent. of moisture,	about 8,000
Petrol (varies according to quality),	about 20,700
Kerosine or paraffin, . . .	20,100
Fuel oil, heavy, .	from 18,600 to 19,600
Hydrogen, ...	62,000
Coal (anthracite), ...	14,700
Coal (bituminous), .	13,600 to 14,000
Coal gas, ...	20,800
Dried oak, ...	7,700
Carbon burned to carbon monoxide,	4,400
Carbon burned to carbon dioxide, .	14,600

If, owing to insufficient air, or to insufficient mixing of air and fuel, the carbon in the fuel is incompletely burnt, some carbon monoxide and smoke (*i.e.*, carbon) may be formed. Carbon monoxide consists of 1 atom of carbon combined with 1 of hydrogen, and is given the symbol CO. If this action takes place 4,400 units of heat are generated. This gas is produced intentionally in producer gas plant described in Chapter IX.

Reference has been made above to the relative proportions of air and fuel (in the form of gas or vapour) necessary for complete combustion. When the two are in the correct proportions combustion is very rapid. An excess of air means a slower rate of combustion. For instance, doubling the quantity of air may mean roughly multiplying the time occupied by the explosion by eight.

Liquid Fuel.—The world's liquid fuel supply is wholly of mineral origin, with the exception of alcohol, which is a vegetable product, and, as a fuel, has not yet progressed beyond the experimental stage in this country. Most of the liquid fuel at our disposal at the present time consists of the natural product known as petroleum or mineral oil, although artificial products prepared by distillation from shale and coal are also to some extent available. For practical purposes, however, liquid fuel means mineral oil, which is chiefly obtained from the United States of America.

In 1913 the world's annual supply of petroleum amounted to 50 million tons, obtained from the following countries :—

	Million Tons.
United States of America, . .	31·4
Russia, ...	9·0
Mexico, ...	3·2
Roumania, ...	1·8
Dutch East Indies, . . .	1·35
Galicia, ...	1·1
India, ...	1·05
Other countries, ...	1·1
Total, . . .	50·0

The crude oil is obtained in liquid form from oil wells of varying depths. In some cases, where the oil field is tending to become exhausted, the wells are from 3,000 to 4,000 feet deep. As found in nature, the crude oil varies widely in appearance and characteristics, although analysis shows that all forms are built up of the two elements, hydrogen and carbon, together with small and negligible traces of sulphur, nitrogen, and oxygen. The ratio in which the two chief elements occur does not vary much, although the properties of the resulting compounds may be very different.

The crude oil is first separated from the sand and water with which it is mixed, and is then subjected to a process of distillation so as to separate the different oils of which it is composed. For the distillation process the oil is placed in a vessel and is gradually heated. As the temperature rises the most volatile hydrocarbons are evaporated, collected in another vessel, and liquified. The hydrocarbons given off at the lowest temperature constitute petrol, or, as it is called in America, gasoline. A further rise of temperature brings over the ordinary lighting oils known as kerosine or paraffin. Next come the solar oils employed in making gas, and also in Diesel engines, and after them the lubricating oils, leaving a pitch-like residue used for asphalt. If the temperature is raised still higher coke remains.

The above is only a very rough classification, owing to the number of different hydrocarbons present, some of them differing very slightly from one another.

Four points are of importance in connection with fuel oil—viz., the specific gravity, flash point, viscosity, and sulphur content.

The specific gravity simply means the weight per unit of volume of the oil as compared with water; thus, 1 gallon of oil having a specific gravity of 0·9 would weigh 9 lbs., whereas a gallon of water weighs 10 lbs. The specific gravity of crude oil varies from 0·78 to 0·97, the lighter oil having a much larger proportion of the more volatile constituents than the heavier oil. Those oils having the lowest specific gravity vapourize most easily, the specific gravity thus gives a useful indication of the ease with which the oil may be volatilized. The specific gravities of various kinds of liquid fuel are given approximately in the following table :—

Petrol,	·65 to ·79
Kerosine,	about ·82
Fuel oil (American),	·886
Fuel oil (Russian),	·956
Benzol,	·88
Lubricating oil,	·84 to ·96

The flash point is that temperature at which the oil begins to give off inflammable vapour. Oils having a low flash point, such as petrol, vapourize readily, but are very dangerous, whereas oils having a higher flash point such as kerosine require heat to vapourize them.

Viscosity or fluidity is simply a measure of the readiness with which oil will flow. The lighter oils flow as freely as water, while the heavier constituents of the crude oil are almost as viscous as tar.

Sulphur.—Some oils are rendered almost useless by the presence of an excess of sulphur compounds, which have a serious chemical effect upon the metal of an engine, and must be removed before the oil can be utilized. The expense of removal of this sulphur is generally very great, and may be prohibitive.

In every country in the world the petrol-driven motor vehicle has increased in use with such rapidity that the demand for petrol or the lighter fractions of petroleum exceeds the supply, or approximates so closely to it that the price has risen to a point which is already making itself felt in checking the adoption of petrol motors for stationery work.

Moreover, the rate of increase of the demand for petrol is such that the supply of fuel available from natural sources is not likely to be sufficient to supply the demand indefinitely.

As a consequence, attempts have been made (1) to utilize some of the heavier constituents of the crude oil, and (2) to secure independent petrol substitutes.

One of the most promising methods for increasing the yield of petrol from heavy distillates is to be found in the so-called "cracking" of the heavier portions, in order to alter their chemical composition and make them yield hydrocarbons of lower specific gravity. Some of these methods have been tried on a practical scale, but their utility is not yet proved.

Another method of utilizing the heavy distillates involves carrying the distillation of petrol further into the kerosine fraction, as is evidenced by the rise in specific gravity of commercial petrol. A few years ago petrol of a specific gravity of ·68 was obtainable in quantity, but at the present day the specific gravity of the petrol in common use for motor cars has risen to ·72, while for heavy commercial vehicles the spirit employed has a specific gravity of ·74. Special care has to be exercised in the use of these heavier spirits, since too great a proportion of the heavier fraction makes it difficult to start the engine when cold. Moreover, in all such mixtures there is the risk of fractional volatilization—that is, the lighter fractions may volatilize and leave the heavier fractions behind.

At the present time the only practically available petrol substitute is benzol, which is obtained as a bye-product in the manufacture of coal gas. Commercial benzol contains sulphur, which has to be removed before it is fitted for motor use. It gives 12 per cent. more power than petrol, and often gives better running. The amount of benzol which can be produced by present methods will probably never be very great compared with the production of petrol.

Gaseous Fuels.—Gaseous fuels suitable for internal combustion engines fall readily into two classes :—

(1) The high-grade fuels, consisting of natural gas and coal gas, which may have calorific values of 500 B.Th.U. per cubic foot or upwards.

(2) The low-grade fuels, such as blast-furnace gas, producer gas, and water gas, the calorific values of which are below 300 B.Th.U. per cubic foot.

The term " natural gas " is applied to any inflammable gas issuing from the earth, but commercially it may be regarded as including only those gases which issue in sufficient quantities and have the necessary heating value to render them of practical use as fuel.

Although very little known in this country, natural gas is found in enormous volumes in the principal oil regions, particularly in the United States. It occurs at various depths, and is generally under great pressure.

Oil engines for use in oil countries are sometimes so constructed that they can utilize natural gas until the supply in the district is exhausted, and can then use oil.

The calorific value of natural gas as first obtained from the earth varies from 1,000 to 1,200 B.Th.U. per cubic foot.

Blast furnace gas is composed largely of carbon monoxide, with traces of hydrogen and sometimes hydrocarbons. There is also present a large proportion of the incombustible gases, nitrogen and carbon dioxide.

Although in the blast furnace the principal actions are those concerned in the smelting of iron when separating it from its ores, the working conditions are such that the coal or coke used for smelting is not completely burnt, and the furnace thus acts as a huge gas producer. At one time blast furnace gas was entirely wasted, but at the present day it is often utilized for heating the air supplied to the blast furnaces, raising steam for operating the plant, or working gas engines for blowing, generating electricity, etc. Blast-furnace gas has been more largely utilized in Germany than in this country.

The gas as first collected carries with it a great deal of dust, which must be removed before it can be used in gas engines. The separation processes are not, however, expensive.

The calorific value of the gas is very low, ranging from 95 to 105 B.Th.U. per cubic foot.

Some of the large engines described in Chap. V. are specially intended for use with blast furnace gas. Since the gas is so poor, the engines are rather large and costly for the power produced, but the cheapness of the gas compensates for this.

Producer gas and water gas are dealt with in Chap. IX.

CHAPTER IV.

GAS ENGINES.

Introduction.—In all internal combustion engines the fuel, if it is to burn properly, must be in the form of a gas or vapour, and in engines of the kind commonly known as gas engines, the fuel is a permanent gas, such as town gas or producer gas. The gas engine is thus distinguished from the petrol or other oil engine, in which the fuel is ordinarily a liquid, and has to be converted into a gas or atomized before it is in a fit condition to burn in the cylinder of the engine. The gas engine thus requires no special vapourizing or injection devices, and is accordingly one of the simplest engines. The gas supplied is mixed with air in suitable proportions, and either the quality or the quantity or both are automatically controlled by the governor, according to the work the engine is required to do.

The earlier gas engines exhibited many striking variations in general design and details, but trial, experiment, and experience have resulted in the survival of practically only one small or medium type—viz., the horizontal engine working on the four-stroke cycle with the cam or half-time shaft lying along the side of the engine. The majority of the small and medium-powered engines of to-day are, in fact, all so much alike that the different makes would only be distinguished from one another with difficulty were it not for the name-plates, and for distinctive features in quite a few details. Similar engines of quite a dozen different makers would not be found to differ materially in the essentials of reliability, first cost, and cost of upkeep.

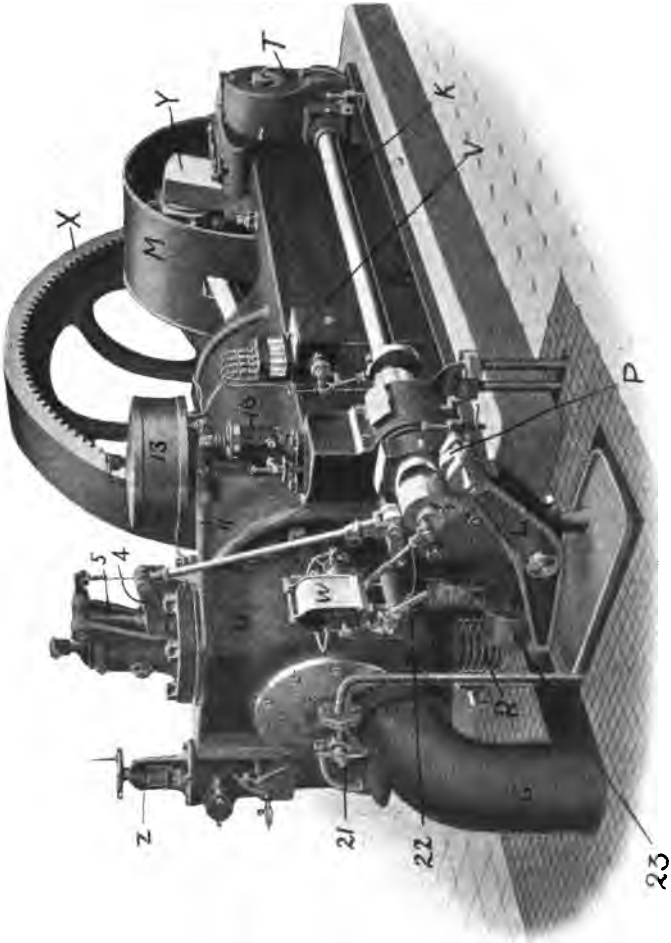


Fig. 11.—Crossley Gas Engine.

The reliability of the modern gas engine is quite remarkable; engine troubles are extremely rare, if the most ordinary care is taken. A possible cause of trouble in a gas engine is the use of gas of poor or variable quality, the latter defect necessitating frequent adjustment of the governor control gear, and thus neutralizing the advantage which a good gas engine possesses that it will work without attention and will automatically adjust itself to the load. Town gas is commonly used for small engines, but its cost is rather high, particularly in districts where the gasworks are small and the area of supply large. Producer gas is cheaper, particularly in the larger sizes, and it is, of course, the only way of producing gas in places where no ordinary gas supply is available. It is, however, not so satisfactory for working, as even with the most careful cleaning and drying, the engines using it suffer from clogging of such parts as ignition points, valves, and pistons much more than engines using town gas. The calorific or heat value of producer gas is also less, necessitating a higher compression, which again militates against good running and easy control. Producer gas plant is dealt with in Chap. IX.

Fig. 11.

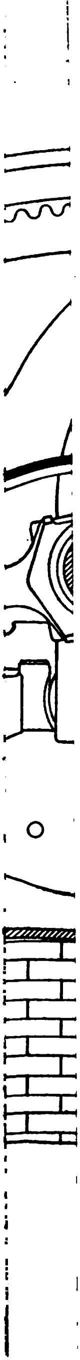
A. Bedplate.
G. Exhaust Pipe.
K. Cam Shaft.
L. Exhaust Rocking Lever.
M. Crank Guard.
P. Exhaust Roller.
R. Exhaust Valve Spring.
T. Gear Wheel Casing.
U. Breech End.
V. Main Lubricator.
W. Magneto.
X. Flywheel.
Y. Crank.
Z. Gas Cock.
4. Radius Lever.
5. Fulcrum Lever.
11. Governor Lever.
13. Governor.
16. Dash Pot.
21. Starter Valve.
22. Ignition Lever.
23. Blow-off Valve Lever.

In this chapter we shall deal with what may be described as the ordinary type of gas engine. Gas engines of large size, intended to develop a high power per cylinder, will be dealt with in Chap. V.

Crossley Single-cylinder Engine.—The firm of Crossley Brothers was one of the earliest to manufacture gas engines working on the Otto cycle. One of their latest single-cylinder horizontal engines will now be described.

Fig. 11 shows a general view of a type of engine made in sizes varying from 70 to 150 brake horsepower, and fig. 12 shows a longitudinal section of such an engine. This engine, and, indeed, all such engines, turn in the direction indicated by the arrow—that is, the piston is moving away from the cylinder when the crank pin S is in the highest position. The crank shaft is mounted in three bearings—one on each side of the crank and a third on the far side of the flywheel. The trunk piston 24 is long, giving a good bearing surface against the cylinder walls, and is fitted with a number of rings—in this case seven. The bedplate A is bolted to a concrete foundation, and is cast with an upper extension B, which encloses the cylinder liner C, the space between the two forming a water-jacket. A groove is formed round the base of the bedplate, to catch any waste oil and prevent damage to the concrete foundation. The breech end or combustion chamber U is bolted to the end of the bedplate casting, and encloses in its upper part the mixture and gas admission valves 1, 3, and in its lower part the exhaust valve F. The combustion chamber and the exhaust pipe G are cooled by means of a water-jacket surrounding them. Water enters at the lowest part of the jackets, circulates upwards, and leaves through the upper pipe H.

On the larger sizes a barring gear or hand-wheel turning gear is provided, so as to turn the engine into a suitable position for starting or for adjustment.



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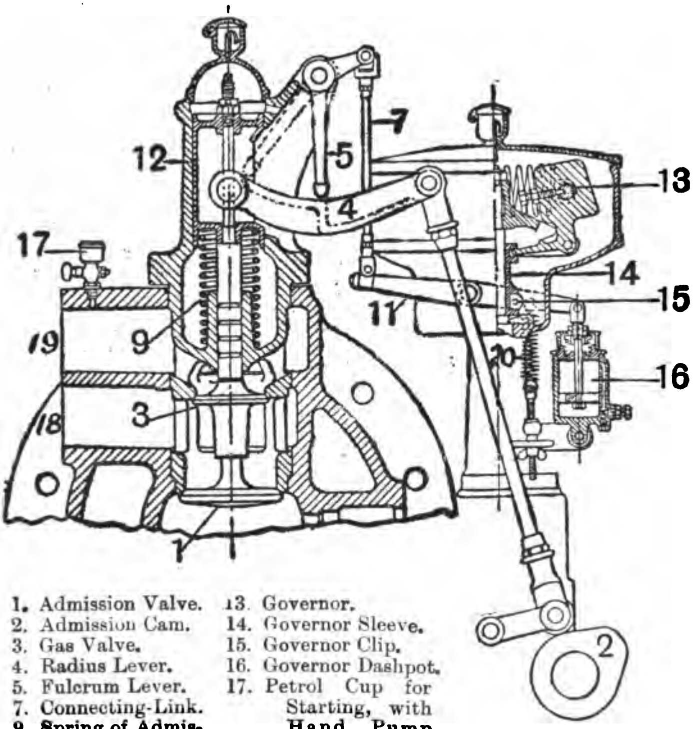
This gear consists of a hand wheel J, with a pinion gearing into teeth on the flywheel rim. It is important that the barring gear be disengaged before starting the engine, or it will be damaged.

A guard M, covering the crank, connecting-rod, and balance weights N, prevents oil being thrown about.

The side shaft or cam shaft K is driven at half the speed of the crank shaft through skew gearing, enclosed in the casing T, and it is provided with two case-hardened steel cams—one for the exhaust valve and the other for the inlet valves. The exhaust cam bears against a hardened roller P on the end of a rocking lever L, the other end of which lifts the valve against the resistance of a spring R. The exhaust roller P can be shifted slightly on its pin, so that it will engage also, when required, a narrow starting or half-compression cam. The exhaust valve F is then, in addition to its ordinary lift, raised during the early part of the compression stroke, so as to allow part of the charge to escape, and thus reduce the compression resistance at starting.

A gas engine is never required to work against a constant resistance; in some cases the variation in the resistance or load is very considerable; for instance, in the case of a gas engine driving a number of lathes or other machines in a workshop, all the machines may be working at one time, and perhaps in less than a minute only one or two, or possibly none may be working. At the same time, whether the engine is driving all the machines or only one machine, it is essential that its speed should vary very little from the normal speed. For these reasons, it is clearly necessary to provide some means for automatically supplying more motive fluid as the load increases, to prevent the engine pulling up or, conversely, to supply less motive fluid as the load decreases to prevent the engine running away. In the

Crossley engine this is effected by a centrifugal governor 13 driven by the engine in conjunction with a gas valve 3 and a mixture valve 1, as shown in fig. 13,



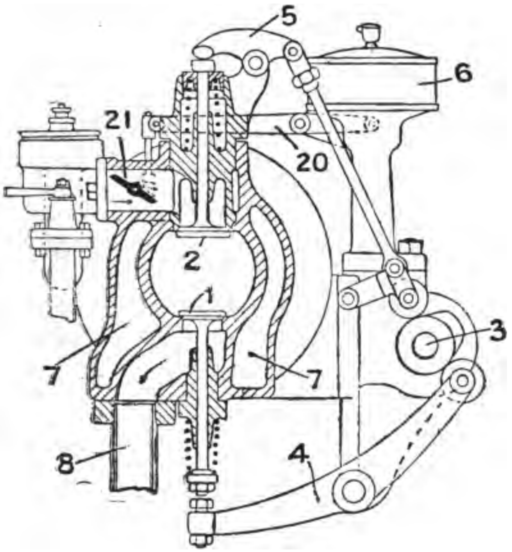
1. Admission Valve.
2. Admission Cam.
3. Gas Valve.
4. Radius Lever.
5. Fulcrum Lever.
7. Connecting-Link.
9. Spring of Admission Valve.
11. Governor Lever.
12. Admission Valve Guide.
13. Governor.
14. Governor Sleeve.
15. Governor Clip.
16. Governor Dashpot.
17. Petrol Cup for Starting, with Hand Pump Starter.
18. Air Passage.
19. Gas Passage.
20. Governor Adjustment Spring.

Fig. 13.—Crossley Gas Engine. Inlet Valves and Governing Gear.

which represents a transverse section taken centrally through the valves. The governor is sensitive to variations of speed, and whenever the speed drops below the no mal, the governor increases the lift of the valves so as to admit a larger quantity of explosive mixture to correspond with the increase of load. The converse action takes place upon decrease of load. The speed of the engine is thus kept very nearly uniform whatever the variations of load. Both valves are secured to the same spindle, the gas valve 3 being the smaller. The action is as follows:—The gas valve regulates the quantity of gas which is allowed to enter from the passage 19 and mix with the air coming along the passage 18, while the mixture valve 1 regulates the quantity of mixture admitted to the cylinder. Thus, he strength of the mixture is regulated, and the quantity of such mixture (whether weak or strong) admitted to the cylinder is also regulated.

The cam 2 bears against a roller and lifts the radius lever 4 by means of the connecting-link, thus causing it to turn about the lower end of the fulcrum lever 5. The mixture valve 1 and the gas valve 3 are in this way opened to an extent depending upon the position of the fulcrum lever 5, which is adjusted by means of a powerful centrifugal governor mounted on a vertical shaft driven from the side shaft. The governor is designed to allow a variation of speed of from 1½ to 2 per cent. above or below normal from no load to full load. When the speed of the governor increases above the normal, the increased centrifugal force causes the revolving weights 13 to move outwards, thus lifting the sleeve 14, the motion of which is transmitted through the lever 11 and link 7 to the fulcrum lever 5, the lower end of which moves to the left, with the resul that the opening of the valves is reduced. When the speed of the engine decreases the action of the centrifugal governor is reversed, and the fulcrum lever 5 is adjusted towards the right. The full load position of the fulcrum lever is shown in full lines, and the light load position in dotted lines.

It should be noticed that the lever 4 only engages the fulcrum lever 5 when it is lifted by the cam; at other times there is a very small clearance between the two, which allows the governor to perform any necessary adjustment of the fulcrum lever 5; but when the lever 4 is being rocked by the cam, the pressure between it and the fulcrum lever 5 holds the latter stationary. The normal speed may be varied slightly by adjustment of the spring 20.

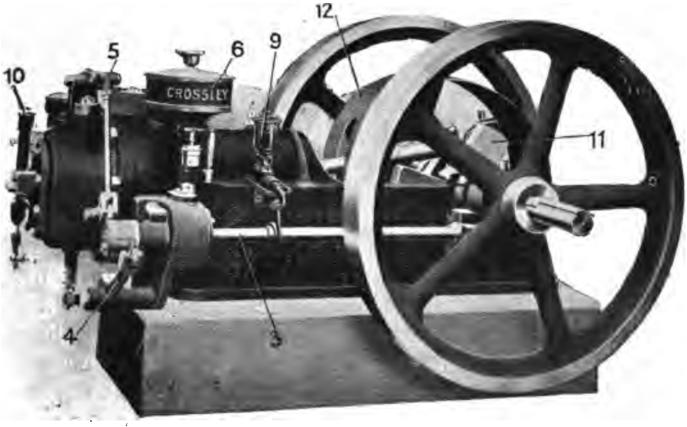


1. Exhaust Valve.
2. Inlet Valve.
3. Cam Shaft.
4. Exhaust Valve Rocking Lever.
5. Inlet Valve Rocking Lever.
6. Governor.
7. Water Jackets.
8. Exhaust Pipe.
20. Governor Lever.
21. Throttle Valve.

Fig. 14.—Crossley Small Gas Engine. Valves and Governing Gear.

To prevent sudden and rapid movements or hunting of the governor, a dashpot 16 is arranged at the end of the lever 11. The dashpot consists of a piston movable in a cylinder filled with oil, the two ends of the cylinder being connected by a passage, which may be more or less closed by a screw. Since the oil can only flow slowly from one end of the cylinder to the other, the resistance to rapid movement of the piston is great, while there is practically no resistance to a slow movement.

Crossley Small Engine.—In the smaller Crossley engines the inlet valve 2 has a constant lift, and the governor acts on a throttle valve 21. Fig. 14 shows a transverse section through the valves and combustion chamber. The governor lever 20 is connected to the throttle valve 21, arranged in the inlet pipe, through which the mixture of air and gas passes. A general view of such an engine is given in fig. 15. These engines are made in sizes developing from 7 to 12½ H.P.,

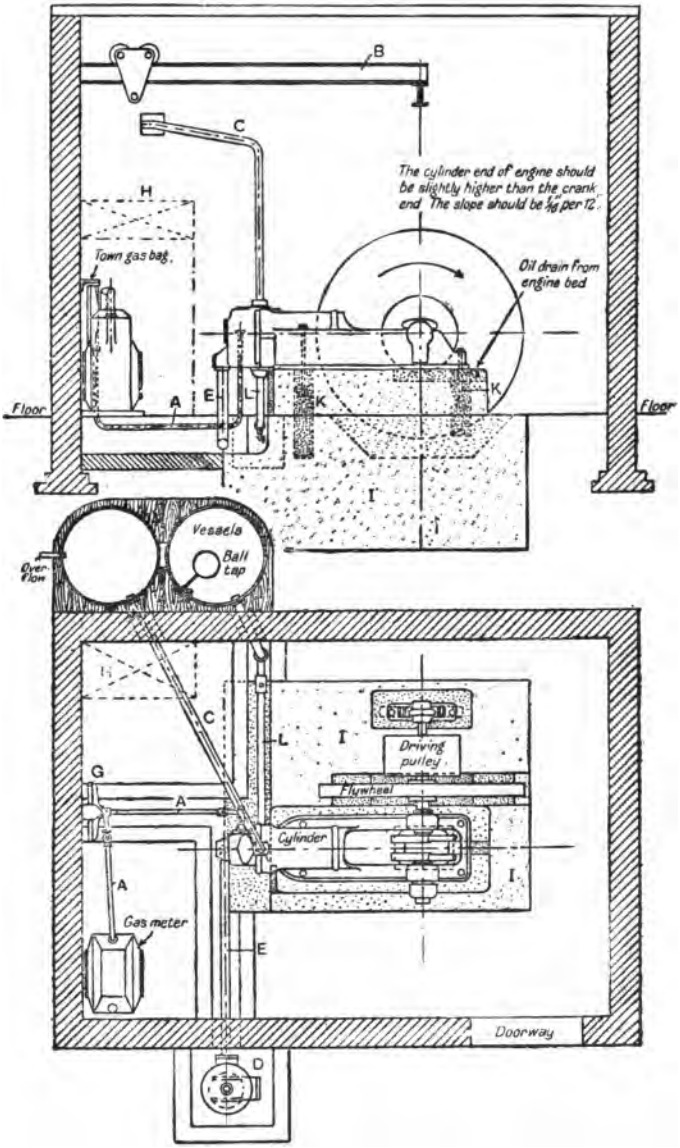


3. Cam Shaft.
4. Exhaust Valve Rocking Lever.
5. Inlet Valve Rocking Lever.
6. Governor.
9. Lubricator for Piston.
10. Hot-tube Ignition.
11. Crank.
12. Crank Guard.

Fig. 15.—Crossley Small Gas Engine.

and may be fitted with either hot-tube or electric ignition. The general arrangement is similar to that of the larger engines previously described. The crank shaft runs in two bearings only, and two outside flywheels are provided.

General Arrangement of Crossley Engine and Appurtenances.—The satisfactory working of a gas engine depends, not merely upon good construction, but upon satisfactory erection and suitable disposition of various appurtenances. Figs. 16 and 17 show a diagrammatic elevation and plan of an engine house for the larger single-cylinder Crossley engines. The engine is bolted down to a massive concrete foundation I by bolts K. The various parts shown are intended for use with an engine consuming town gas, which is led through a gas meter to the engine by a pipe A, connected at some point to a gas bag G having one side of flexible rubber. The object of this gas bag is to make the flow of gas through the meter fairly regular since the suction of the engine is intermittent. The water tanks for the engine cooling water are cylindrical in form, and rest on a wooden stand. Their position with respect to the engine is such as to ensure a natural circulation, the heated water from the engine cylinder passing to the top of one tank by a pipe C, which slopes upwards at every point, and returning to the engine by a pipe L from the bottom of the other tank. Partitions are arranged in the tanks to compel the water to take a circuitous path, and thus cool it more rapidly. A carriage running on a steel joist B over the engine facilitates the lifting of the parts when overhauling. To adapt the engine for working with benzine or petrol, the gas bag and meter are not required, but a fuel tank H and carburetter with a connecting pipe between the two are provided.



The cylinder end of engine should be slightly higher than the crank end. The slope should be 1/16" per 12".

Figs. 16 and 17.—General Arrangement of Crossley Engine.

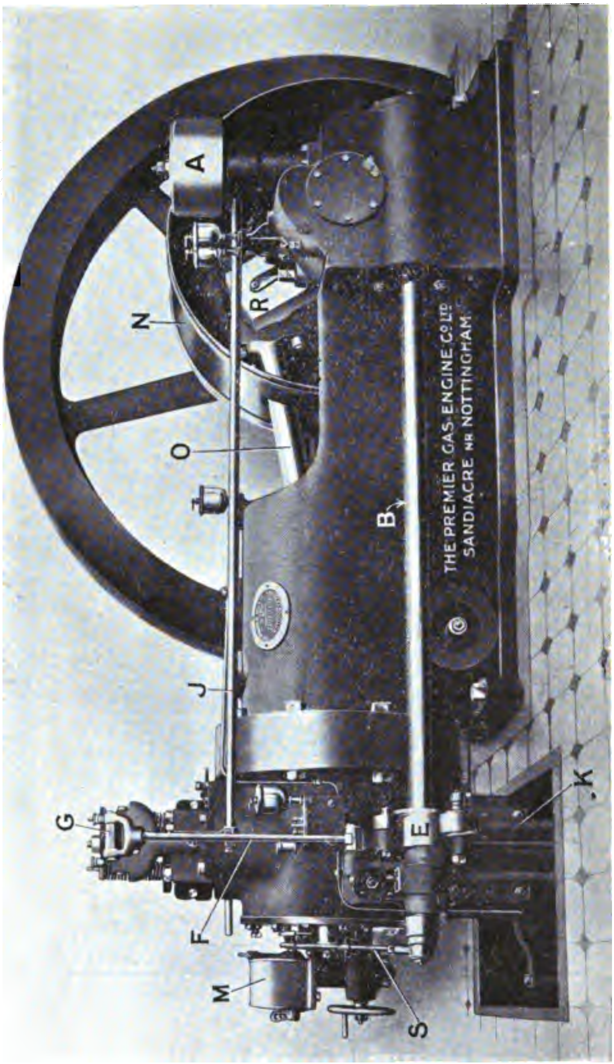


Fig. 18.—Premier Gas Engine.

The exhaust gases are led by the pipe F to an exhaust box or silencer D outside the building, this box being designed to allow the gases to expand slowly, and thus prevent noise.

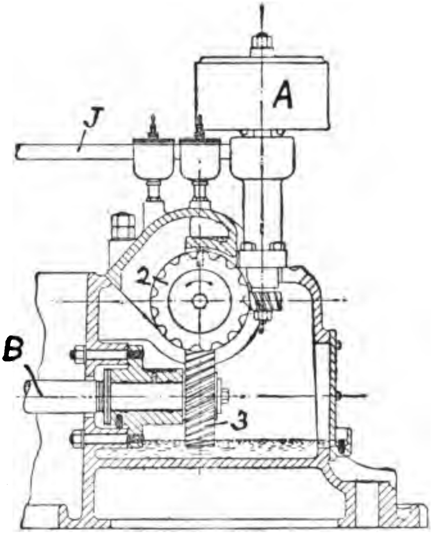
Premier Single-cylinder Engine.—A general view of a Premier gas engine made in sizes from 33 to 125 H.P. is shown in fig. 18. The enclosed centrifugal governor A is disposed vertically at the crank-shaft end of the engine, and is driven directly from the crank shaft through skew gearing shown in section in fig. 19.

Fig. 18.

A. Governor.
B. Cam Shaft.
E. Cams.
F. Adjustable Rod.
G. Inlet Valve Rocking Lever.
J. Governor Control Spindle.
K. Exhaust Valve Rocking Lever.
M. Magneto.
N. Crank Guard.
O. Connecting-rod.
R. Crank.
S. Magneto Operating-rod.

The cam shaft B is also driven through skew gearing, the wheel 2 on the crank shaft serving to drive both the governor and cam shafts. The whole of this gearing is completely enclosed, and the skew wheel 3 on the cam shaft dips continually in oil.

The power is regulated by varying the lift of the gas and air inlet valves, the valves, valve gearing, and combustion chamber being shown in section in fig. 20. The gas valve C is formed with a ring, which controls the opening of the air ports P, and these parts are mounted on the spindle of the mixture valve D, so that they can move slightly on the spindle under the action of a spring. This ensures that both valves engage their seatings properly. It will thus be seen that the variation of the lift or stroke of the valves regulates (*a*) the quantity of gas passing the gas valve C, (*b*) the quantity of air admitted through the ports P, and (*c*) the quantity of mixture passing the valve D.

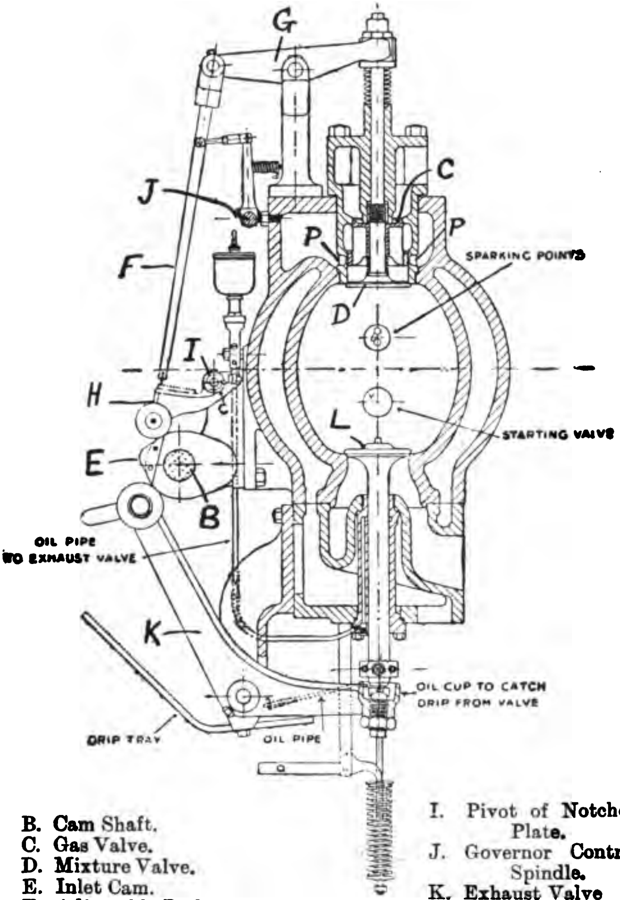


A. Governor.
B. Cam Shaft.
J. Governor Control Spindle.
2. Gear Wheel on Crank Shaft.
3. Gear Wheel on Cam Shaft.

Fig. 19.--Premier Gas Engine.

The valve spindle is depressed by means of the cam E, through the medium of the notched plate H pivoted at I, the rod F, and the rocking lever G.

The stroke of the admission valves is controlled by the governor, which turns the spindle J and swings the rod F in such a manner that, when the speed of the engine increases, the hardened end of the rod F engages the hardened notched plate H nearer to its fulcrum I, and thus a smaller charge is admitted. When the speed falls the rod F engages further from



B. Cam Shaft.
C. Gas Valve.
D. Mixture Valve.
E. Inlet Cam.
F. Adjustable Rod.
G. Rocking Lever.
H. Notched Plate.
I. Pivot of Notched Plate.
J. Governor Control Spindle.
K. Exhaust Valve Rocking Lever.
L. Exhaust Valve.
P. Air Admission Ports.

Fig. 20.—Premier Gas Engine. Valve Gear.

the fulcrum, and the charge admitted is increased. The exhaust valve is operated from the cam shaft through the rocking lever K, and the valve itself in the larger sizes is prevented from burning by water circulated inside it. This water cooling also renders it possible to lubricate the stem of the valve as shown. Each of the valves is provided with two springs, and, in the event of breakage of either spring, the other will keep the engine going while a new spring is put in.

Premier Single-cylinder Scavenging Engine.—In Chapter II. reference was made to the loss of efficiency in two-cycle engines due to the mixing of the incoming charge with a residue of the exhaust gases. This action also takes place, although to a smaller extent, in engines working on the four-stroke cycle, some of the exhaust gases being left in the clearance space and mixing with the fresh charge. In the engine now under consideration, the products of combustion are swept out by a charge of air forced through the clearance space. The incoming charge of gas and air is thus not contaminated by the exhaust gases, but is mixed with pure cool air, which can support combustion, and also cools the cylinder. This operation is referred to as scavenging. The Premier scavenging engines are made in sizes developing 150, 200, and 250 H.P., these powers being unusually high for a single-cylinder gas engine.

A sectional view of a 150 H.P. Premier scavenging engine is given in fig. 21, the flywheel of this engine being provided with grooves for driving ropes. Fig. 22 shows a transverse section on the centre line of the inlet and exhaust valves E, H. With the exception of the use of a scavenger charge, the cycle of operations is the usual four-stroke one, and the action will be readily understood on referring to the drawings in conjunction with the following description :—

A.	Scavenging Piston.	H.	Exhaust Valve.
C.	Air Passage to Motor Cylinder Z.	I.	Balance Woights.
D.	Ports leading to Scavenging Cylinder N	J.	Piston Cooling Water Pipes.
E.	Admission Valve.	M.	Gas Passages.
F.	Air Admission Valves.	N.	Scavenging Cylinder.
G.	Gas Valve.	P.	Air Ports.
		Q.	Crank Guard.
		S.B.	Air Supply Pipe.

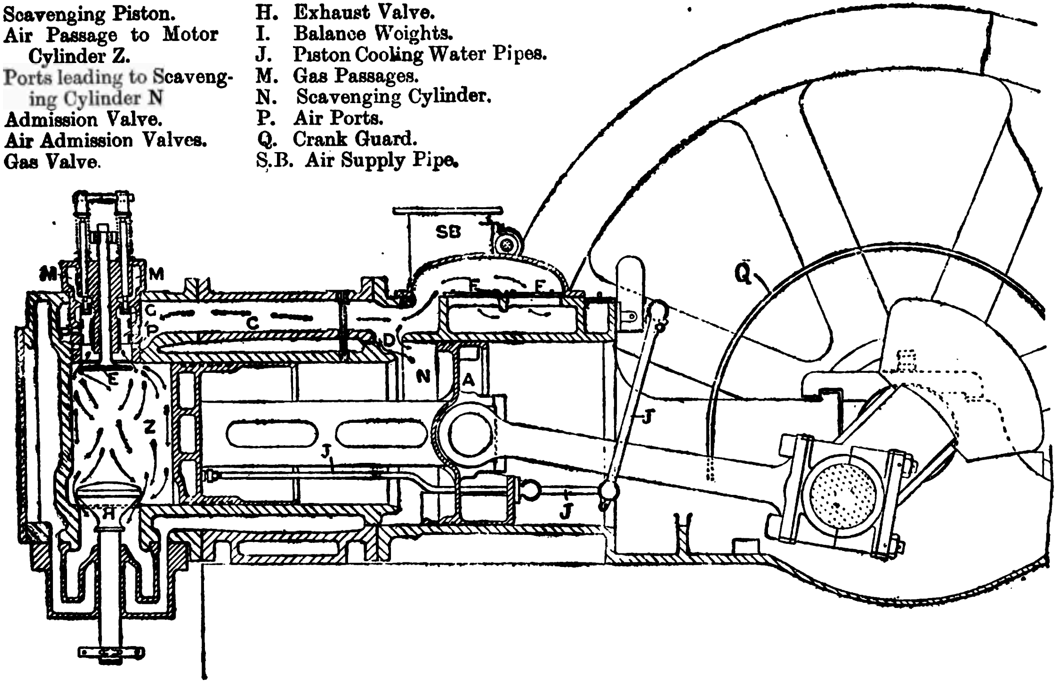


Fig. 21.—Premier Scavenging Engine.

First Stroke.—Assuming that the engine is commencing its first or suction stroke, the admission valve E will be open, exhaust valve H nearly shut, and the annular gas valve G shut, but opening when the piston has moved a small distance on the suction stroke. The air supply is admitted through a pipe S B, and thence through light lift valves F.

It will be seen that the piston is of the differential type, and, therefore, that, when it moves forward, the air entering through the valves F will divide up, a portion entering the enlarged cylinder N by way of the port D, and another portion going through the passage C, ports P P, and valve E to the motor cylinder Z. The gas is fed through a pipe and gas cock O to the space M, whence it passes through the annular gas valve G, past the air ports P P, where it meets and mixes with the entering air. Towards the end of the stroke the gas valve is closed, and shortly thereafter the admission valve E also; at this stage the cylinder is filled with a mixture of air and gas.

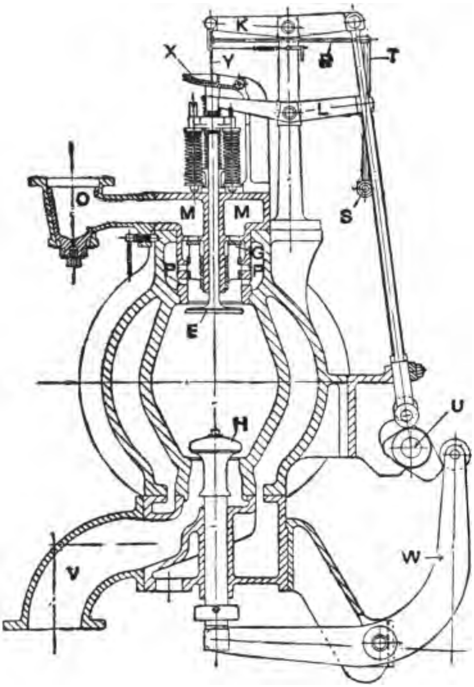
Second Stroke.—The mixture is compressed into the clearance space of the cylinder Z, while the air which entered the scavenging cylinder N is also compressed, but. owing to the comparatively large volume of the clearance spaces in connection with it, the pressure behind the piston A rises to only about 5 lbs. above atmospheric pressure, whereas the pressure in the clearance space Z rises to between 100 and 180 lbs., depending on the volume of this space, which is made suitable for the kind of gas used.

Third Stroke.—When the compression stroke is nearly completed, the compressed mixture is ignited by means of an electric spark, and the piston is propelled forward, the air which had been compressed by the piston A expanding and falling again to atmospheric pressure. Towards the end of this stroke the exhaust valve H is opened, and the pressure in the motor cylinder falls nearly to that of the atmosphere.

Fourth Stroke.—The piston moves backwards, expelling the products of combustion from the motor cylinder and recompressing the air behind the large end of the piston A till the crank reaches the point shown on the diagram. At this point the admission valve E is opened and the air compressed by the piston A flows through the ports P P and the valve E, spreading out and displacing the products of combustion in the upper part of the space Z, as indicated by the arrows. The continued backward movement of the piston keeps up the supply of air, which flows at an increasing rate through the diminishing space Z, and eventually clears out all the products of combustion from that space, and fills it with pure and comparatively cool air. A considerable excess of air is supplied by the piston A to ensure the complete clearing out of the space Z, and this excess passes through the exhaust valve, which remains open until after the crank has passed the dead centre to allow the pressure in the cylinder to fall to that of the atmosphere. The space Z is, therefore, filled with pure and cool air instead of hot products of combustion. The passage of a large excess of cool air over the valves and internal surfaces, which come in direct contact with the flame, also helps to cool these surfaces, and thus in two ways tends to prevent that overheating which is the greatest difficulty met with in large engines.

Admission Valves and Governing Gear.—The cross-section through the admission and gas valves (Fig. 22) will make the construction of the valve operating mechanism clear.

It will be seen that the gas valve G is an annular one, having a double seat and double opening, and that it has rings attached to it, which partially block the air admission ports P when the gas valve opens. Thus it results that the greater the stroke of the gas valve, the greater is the passage for gas and the less the passage for air, and when the gas valve is closed, the air ports are full open, which allows a free passage for the scavenging air.



E. Admission Valve.
G. Gas Valve.
H. Exhaust Valve.
K. Gas Valve Rocking Lever.
L. Admission Valve Rocking Lever.
M. Gas Passage.
O. Gas Cock.
P. Air Ports.
R, T, S. Connections to Governor.
U. Cam Shaft.
V. Exhaust Passage.
W. Exhaust Valve Rocking Lever.
X. Notched Plate.
Y. Adjustable Blade.

Fig. 22.—Premier Scavenging Engine. Valves and Governing Gear.

The admission valve is operated by the lever L, and the gas valve by the lever K, through the medium of the blade Y, which is connected to the governor by means of the rod R and lever arm T, keyed to the spindle S, which is adjusted angularly by the governor.

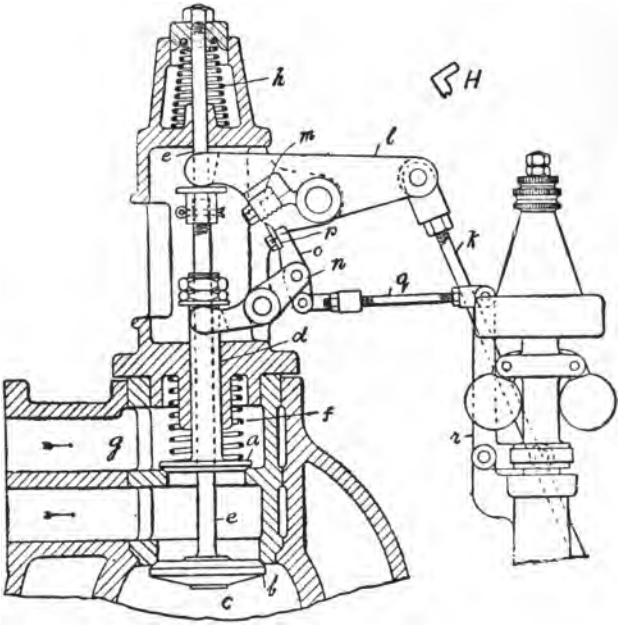
When the governor rises the blade Y is moved to the left, thus engaging with the notched plate at a greater distance from the fulcrum of the arm X, to which it is attached, and consequently reducing the opening of the gas valve, while a fall of the governor throws the blade Y to the right and increases the gas valve opening. When the blade is moved to the greatest extent it misses the plate altogether, and no gas is admitted. This constitutes a combined variable mixture and hit-and-miss arrangement, the latter coming into play only at light loads, when the variable mixture arrangement alone would be very uneconomical.

The exhaust valve and the compound or differential piston are both water-cooled, the method of cooling the piston being similar to that described in connection with the Premier tandem engine in the next chapter.

Robson Admission Valves and Controlling Mechanism.—The gas engines previously described have been controlled by varying the lift of the admission valves, or by using an ordinary throttle valve in the mixture conduit. In the Robson engine the power of the engine is controlled by the governor by mechanism which can act on the variable "quality" principle or the "hit-and-miss" principle. Fig. 23 shows the inlet mechanism as adapted for quality governing. The gas passing along the upper passage *g* is admitted by the valve *a*, which is given a variable lift controlled by the governor. Air passing along the lower inlet passage mixes with the gas, and the mixture is admitted to the cylinder *c* by the valve *b*, which is given a constant lift from a rocking lever *l* actuated from the cam shaft by the link *k*. The long stem *e* of the valve *b* is pulled upwards by a spring *h*.

The gas valve *a* has a hollow stem *d*, which slides on the stem *e* of the mixture valve *b*; it is forced downwards by a spring *f*.

The lift of the gas valve *a* is controlled by the governor by means of the mechanism now o be described. The upper end of the hollow valve stem is raised by the left arm of the rocking lever *n*, the right arm of which carries hinged to it a short finger *o*



a. Gas Valve.
b. Mixture Valve.
c. Engine Cylinder.
d. Stem of Gas Valve *a.*
e. Stem of Valve *b.*
f. Spring of Valve *a.*
g. Gas Passage.
h. Spring of Valve *b.*
l. Rocking Lever for Valve *b.*
m. Stepped Block.
n. Rocking Lever for Valve *a.*
r, *q*, *o.* Governor connections.
p. Pecker.

Fig. 23,—Robson Admission Valves and Controlling Mechanism connected to the governor at its lower end by the link *q*. The upper end of the finger *o* carries a "pecker" *p*, which consists of a hardened steel piece with a V edge. This pecker is engaged by any one of several steps or notches in a stepped block *m* carried by the rocking lever *l*. The movement of the rocking lever *l* thus depresses the pecker, and so operates the rocking lever *n* and lifts the gas valve *a*. The vertical arm *r* of a bell crank lever forming part of the governor gear adjusts the link *q* according to the speed, and so tilts the rocking lever *o* that the pecker *p* engages the block *m* closer to or further from the fulcrum of the lever *l*. When the speed of the governor increases beyond the desired amount, the bell-crank lever *r* tilts the finger *o* so as to move the pecker further to the right, with the result that the finger is depressed at a later moment in the cycle of operations, owing to the inclination of the stepped face of the block *m*. The opening of the gas valve is consequently delayed and the lift reduced, and the charge admitted to the cylinder is weakened.

There is no throttling action; a full charge of air enters the cylinder under all conditions. The quantity of gas is, however, varied, so as to vary the strength or quality of the mixture.

The mechanism can be adapted for "hit-and-miss" governing by replacing the stepped block *m* by a block having one groove only, of the shape shown at H. With the ordinary load the pecker is engaged by the groove every time it descends, but with increase of speed the pecker is moved by the governor slightly to the right, so that it misses the groove, and the gas valve is consequently not lifted. A full charge of pure air is then admitted to the cylinder. As soon as the speed decreases, the pecker again catches the groove in the block H, and a charge of gas is admitted.

Starting Apparatus.—An internal combustion engine at starting has to be turned by hand or by some external source of power, so that the suction and compression strokes may be performed as a preparation for the first working stroke, after which the inertia of the flywheel keeps the engine going until the next working stroke.

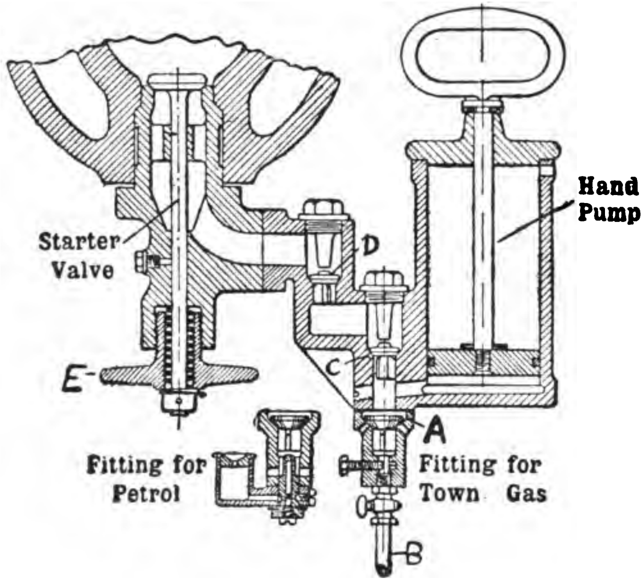


Fig. 24.—Hand Pump Starter.

In the smaller sizes the engine can be turned directly by means of the flywheel, but in the larger sizes it is necessary (*a*) to pump an explosive charge into the cylinder, or (*b*) to work the engine by admitting compressed air during the working stroke until the necessary charge is drawn in and fired in the ordinary way, or (*c*) to turn the engine by a small independent motor, such as a petrol engine or an electric motor.

Hand Pump Starter.—Fig. 24 shows the former method applied to a Crossley gas engine. The piston of the pump is worked up and down by hand, and on the up-stroke draws into the pump cylinder through the non-return lift valve A a mixture of gas and air. The gas enters by the pipe B, and the air through holes in the valve seat. On the down-stroke the mixture is forced into the cylinder past the two non-return valves C, D, and the starter valve.

The following operations are performed at starting :—

(1) The crank shaft is set so that the piston has covered about a third of the working stroke, all the valves then being closed. The blow-off valve is opened, if necessary, to relieve compression.

(2) The pinion of the barring gear (if such gear is employed) is disengaged from the teeth in the rim of the flywheel.

(3) The ignition gear is so set in the starting position that it will give a spark in the cylinder as soon as the piston moves.

(4) The exhaust roller on the end of the rocking lever is put under the starting or half-compression cam.

(5) The hand screw E on the starter valve is screwed back, so as to allow the valve to lift when necessary.

(6) The blow-off valve, if provided, is then opened, otherwise the exhaust valve must be wedged open to allow the air in the cylinder to be replaced by a mixture from the pump.

(7) The pump is worked by hand, 30 to 80 strokes being given, according to the size of engine; the cylinder should then contain a suitable explosive mixture.

(8) The blow-off valve is shut or the exhaust valve closed.

(9) The pumping is continued until the pressure in the cylinder is sufficient to move the piston; the

magneto will then give a spark, which will ignite the mixture, and start the engine.

(10) The ignition lever is quickly moved to the "late" firing position in time for the next working stroke.

(11) The starter valve is screwed on to its seat.

(12) As the engine speeds up, the exhaust roller must be moved away from the starting cam, so that full compression is obtained.

(13) The ignition lever is finally moved to the "early" position.

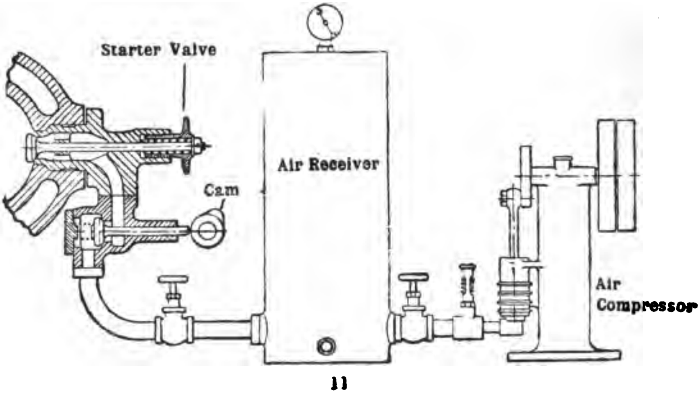


Fig. 25.—Compressed Air Starter.

Petrol may be used for starting instead of gas. The fitting for petrol which then replaces the fitting for town gas is a simple form of carburetter. Petrol is poured into the cup on the left, and is drawn through the central jet on the right by suction due to the flow of air through the valve A.

Compressed Air Starter.—In the automatic compressed-air cam-controlled Crossley starter, shown in fig. 25, the compressed air is stored in an air receiver, into which it has been compressed by a one-stage air compressor driven by a small engine or (as shown) by a belt from a pulley on the engine shaft or a countershaft.

When starting, the operations set out under the heading (1) to (5) in connection with the hand-pump starter must first be performed. The compressed air is then turned on quickly by means of the valve, so that it will at once enter the cylinder and start the engine. After the first few revolutions the compressed air is shut off and the operations (10) to (13) enumerated above must then be performed. The starting cam worked from the cam shaft opens the valve during each working stroke.

Hot-tube Ignition.—Electric ignition is now generally fitted on gas engines, but the timing valve and hot-tube method is still in use, and is sometimes supplied with the smaller sizes. This method was brought to a high state of perfection in the early days of the gas engine.

An igniter supplied by the Crossley Company with their small gas engine, as an alternative to electric ignition, is shown in fig. 26. A gas flame A keeps the porcelain tube B at a dull red temperature, and the compressed mixture is admitted to this tube by the timing valve at the correct instant. The tube, burner, and flame are protected by a casting having air holes D at its lower end and openings E at the top end. The ignition device is secured to the end of the combustion chamber, as shown in fig. 15.

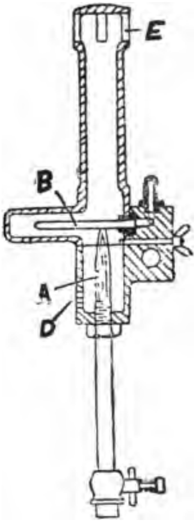


Fig. 26.—Hot-tube Ignition.

Lubrication.—The question of lubrication is so important in relation to the economy, life, and reliable working of an engine that it is proposed to devote a short section to this subject.

The parts on which the greatest wear is likely to occur, and which, therefore, require special treatment, are as follows :—

(1) The skew or bevel gear for driving the cam shaft or governor shaft.
(2) The piston and cylinder.
(3) The crank-shaft and cam-shaft bearings.
(4) The crank pin.
(5) The piston or gudgeon pin.

The lubrication of these parts will now be considered in detail.

The skew or bevel gearing is invariably completely enclosed, and one of the wheels dips in an oil bath, as shown in fig. 19 in connection with the Premier engine.

In the large Crossley engine, illustrated in fig. 11, the main lubricator V consists of an oil reservoir and force pumps worked by an eccentric from the cam shaft. Oil is forced through four sight feed glasses, and four pipes lead respectively to the piston and cylinder, the piston pin, the crank pin, and the exhaust valve. The amount of oil delivered to each of these parts is independently adjustable.

In the Crossley engine, shown in the sectional view (fig. 12), the piston and cylinder are, as before, lubricated by oil forced through the passage 29, but the piston pin is lubricated from the drip lubricator 27 acting in conjunction with the oil-way shown on the piston.

The small Crossley engine shown in fig. 15 has forced lubrication for the piston and cylinder only.

Fig. 27 shows a ring oiler for the crank-shaft bearing of a Hornsby gas engine of 11 or more B.H.P. The bearing is made with two grooves, to accommodate two light metal rings, which rest on the shaft and dip into

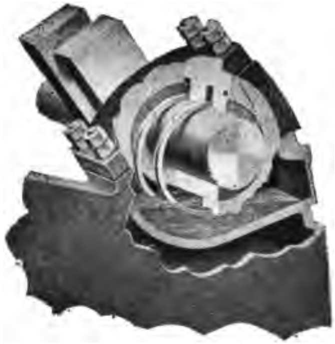


Fig. 27.—Lubrication of Crank-shaft Bearing.

an oil bath at their lower edges. The rings turn with, but more slowly than, the shaft, and carry oil up to the bearing. In some engines chains are used instead of rings.

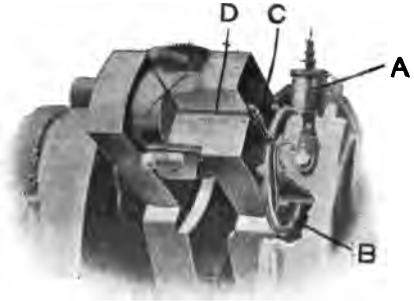


Fig. 28.—Crank-pin Lubrication.

Fig. 28 shows a centrifugal ring oiler for the crank pin of a Davey, Paxman gas engine. Oil from a reservoir A is fed slowly through a pipe and drips into a ring B, which turns with the crank shaft, and is concave or hollow on the inside. The oil, under the action of centrifugal force, flows outwards to the crank-pin bearing through the pipe C and oil-ways D drilled in the crank pin, which is shown partly in section.

The various other parts of an engine are supplied with drip or needle lubricators or merely oil holes.

CHAPTER V.

LARGE GAS ENGINES.

Introduction.—The single-cylinder gas engines described in the previous chapter are seldom made in larger sizes than about 150 H.P. Greater powers are obtained in the following ways :—

(*a*) Two, three, or four horizontal cylinders are coupled together so as to work on the same crank shaft.

(*b*) The engines are made double-acting.

(*c*) The two-stroke cycle is adopted.

(*d*) Two cylinders are placed tandem fashion—that is, one cylinder is arranged behind and co-axial with the other, the two pistons having a common piston-rod connected to a single crank.

(*e*) Two pistons are placed in the same cylinder.

(*f*) Two, three, four, or six vertical cylinders are arranged to work on the same crank shaft.

(*g*) Several pairs of tandem vertical cylinders are arranged to work on one crank shaft. In one such engine made by the National Gas Engine Company, twelve cylinders work on a six-throw crank shaft, the cylinders being arranged in pairs tandemwise one above the other, the two cylinders of each pair working on one crank.

The objection to the use of cylinders of large size for internal combustion engines is principally due to the difficulty of keeping the cylinder and other parts (particularly the piston and exhaust valve) cool enough. In a small engine the area available for cooling (that is, the curved surface of the cylinder) is fairly large in comparison with the volume or contents of the cylinder. As the cylinder is made larger, the volume increases more rapidly than the cooling area. As an example, consider two cylinders of the same length but one twice the diameter of the other; the larger cylinder has four times the volume of the smaller, but only twice the cooling area.

As the sizes of cylinders increase, it thus becomes more and more difficult to devise satisfactory cooling arrangements. The mere jacketing of the cylinder and valve chest is insufficient, and arrangements have generally to be made to circulate cooling water through the piston and exhaust valve.

A few examples will now be described in which one (or more) of the features enumerated above under the headings (*a*) to (*g*) is embodied.

Premier Tandem Scavenging Engine.—In this engine, which is shown in section in fig. 29, two single-acting cylinders are placed one behind the other, the Otto cycle of operations being followed. The working strokes of the cylinders are alternate, so that there is one working stroke in each revolution, and the crank shaft receives impulses twice as often as it would in the case of a single-cylinder engine.

This engine is made in sizes developing from 400 to 1,200 H.P.

The different operations taking place in the cylinders during a cycle of two revolutions are shown in the following table:—

		Front Cylinder.	Back Cylinder.
First Revolution,	Forward stroke	Suction	Working
	Return stroke	Compression	Exhaust
Second Revolution	Forward stroke	Working	Suction
	Return stroke	Exhaust	Compression

B. Exhaust Valves.
C. Crank.
D. Pump Operating-Rod.
E. Admission Valves.
F. Air Valve.
G. Pump Piston.
H. Gas Passages.
J. Main Pistons.
K. Piston Cooling Water Pipes.
L. Piston-rod.
M. Flywheel.
N. Water Jackets.
G. Exhaust Pipes.
P. Scavenging Pump.

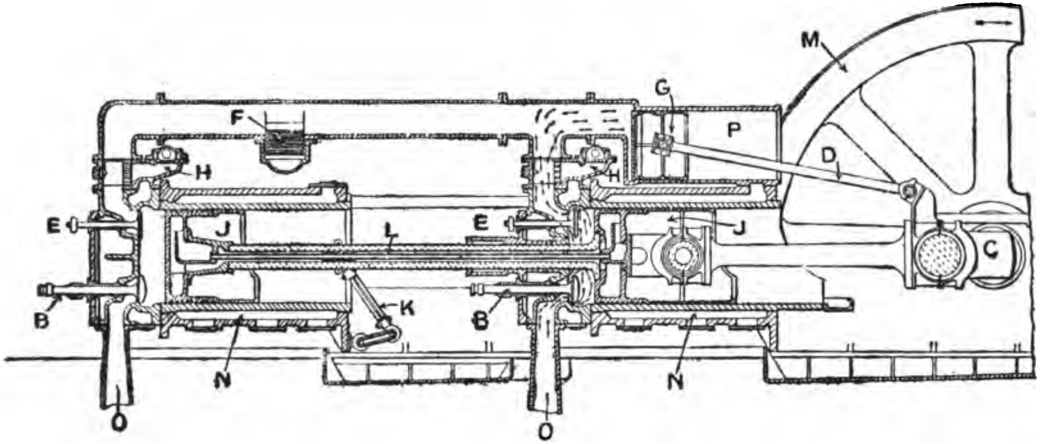


Fig. 29.—Premier Tandem Scavenging Engine.

In addition to the ordinary operation of the Otto cycle, there is a positive scavenging operation similar to that described in Chap. IV. in connection with a single-cylinder Premier engine.

Towards the end of the exhaust stroke the admission valve E is opened and air compressed in the passages behind this valve flows into the combustion chamber or clearance space, driving out before it, through the exhaust valve B, the products of combustion resulting from the previous explosion, as shown by the arrows on the front cylinder.

The air for scavenging is compressed to a pressure of about 3 lbs. per square inch (before the opening of the valve E) by a pump P placed above the engine, and operated from the main crank C by means of a rod D jointed to the big end of the connecting-rod. After the admission valve E opens, the pump piston G continues its motion and keeps up a steady flow of air, and this action is continued till the crank has passed the dead centre and the suction stroke has commenced. The exhaust valve B is now closed, and the pressure in the air pipe having fallen below atmospheric pressure, air is drawn through an inlet valve F, part of this air passing to the motor cylinder and on its way mixing with the gas admitted through the passage H by a separate valve, and part going to the scavenging air pump, the piston G of which is also moving forward.

The same action is repeated during the next revolution, but the back cylinder receives the air from the pump.

Thus each cylinder is scavenged after every explosion—that is, the foul gases are swept out by a charge of air forced positively through the combustion chamber, the one air pump serving to scavenge both motor cylinders. The products of combustion left in the combustion chamber of a non-scavenger engine are very hot, and by expelling these by cool air, as in the present engine, the combustion chamber is filled previous to the admission of the explosive charge with cool air instead of hot products of combustion, and thus the risk of too early ignition of the entering charge is avoided.

The explosive charge is not only cooler, but consists of gas and air only, not gas and air contaminated with products of combustion, and is, therefore, a purer combustible mixture, and the power developed by the explosion is greater than in non-scavenging engines.

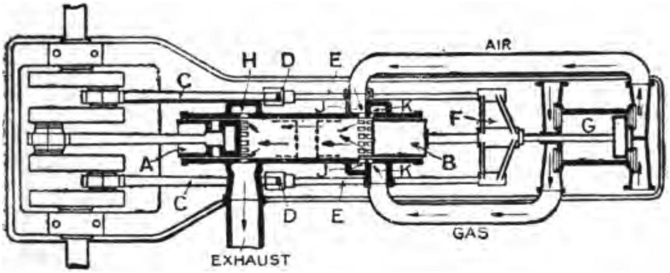
As a considerable volume of air is forced through the valves and combustion chamber, and impinges against all the internal heated surfaces, it cools these surfaces and increases the life of the valves.

The valves E, B are placed in the ends of the cylinders and are operated by cams. Both pistons J are hollow, and are cooled by water circulating through them, this water being supplied to and taken away from the pistons through jointed pipes K connected to the hollow piston-rod L at about its middle. The water passes through one of the jointed pipes to the central pipe in the piston-rod, and flows in both directions to the two pistons. It returns through a hollow annular space in the piston-rod, and passes away through a second jointed pipe. The pistons are internally cored in such a way that the water flows all over the surface exposed to the hot gases.

The Oechelhauser Two-Stroke Engine.—We have now to consider an engine in which high power is obtained from a single cylinder by the adoption of the two-stroke cycle and the use of two pistons in the one cylinder. This engine is of German origin, and is named after its inventor. Messrs. Beardmore, of Glasgow, have manufactured in this country engines of various sizes developing from 400 to 1,500 H.P. in one cylinder, or double these powers if two cylinders are employed. The 1,500 H.P. engine has a cylinder 42 inches in diameter, and each piston has a stroke of 51 inches. It is thus equivalent in size to a cylinder 42 inches in diameter, with a single piston having a stroke of 102 inches. A flywheel suitable for use when the engine drives a dynamo would have a diameter of 20 feet and a weight of 100 tons, and the overall length of the engine, including the flywheel, would be 56 feet. The weight of the engine without the flywheel is 180 tons. Where two engines of this size are coupled together so as to work on one crank shaft a single flywheel weighing only 70 tons is placed on the crank shaft between them. This reduction in the weight of the flywheel is due to the fact that there are two working strokes in each revolution instead of one. The cylinders act alternately, so that there is always some turning effort acting on the crank shaft except at the dead centres, whereas in the case of a single-cylinder engine the mass or inertia of the flywheel has to effect the return stroke of the pistons.

A diagrammatic sectional plan of an engine is shown in fig. 30. Both pistons move towards and away from one another simultaneously, the front piston A being connected directly to the middle crank, while the back piston B is driven from the two outer cranks through two connecting-rods C, crossheads D, side rods E, and a back crosshead F. The piston-rod for the back piston B is also extended to work a double-acting pump G, the inner end of which supplies gas to the main cylinder, while the outer end supplies air. The two pistons A, B are shown in full lines in their outermost positions, and the dotted lines show them in their innermost positions with the charge fully compressed.

There are no valves in this engine; the burnt gases are exhausted, and the air and gas admitted through ports which are uncovered by the pistons themselves when the latter are in their outermost position. The inner piston A controls a ring of ports, which allow the exhaust products of combustion to escape into an annular space H surrounding the cylinder and connected to the exhaust pipe. The outer piston B controls (1) a ring of ports J, which connect the cylinder with the air supply from the pump G, and (2) another ring of ports K slightly further out, which connect the cylinder with the gas supply.



A. Front Piston.
B. Back Piston.
C. Connecting-rods.
D. Crossheads.
E. Side-rods.
F. Back Crosshead.
G. Air and Gas Pump.
H. Exhaust Belt.
J. Air Ports.
K. Gas Ports.

Fig. 30.—Oechelhauser Two-stroke Engine.

The cycle of operations is as follows :—

Working Stroke.—The pressure in the cylinder during the working stroke forces the two pistons apart, so that each exerts a turning effort or torque on the crank shaft.

Exhaust.—Towards the end of the stroke the front piston A uncovers the exhaust ports, thus allowing part of the exhaust gases to escape, that which remains in the cylinder being reduced to the pressure of the atmosphere.

Scavenging.—After a very short interval the back piston B uncovers the air ports J at the other end of the cylinder, and admits air which has been stored in the receivers surrounding the ports at a pressure of from 5 to 7 lbs. per square inch above the atmospheric pressure. The air first admitted serves to scavenge the cylinder—that is, to force out before it the residue of the products of combustion through the ports at the exhaust end of the cylinder.

Admission of Gas.—After a further short interval the gas ports K are uncovered by the back piston B, and gas, which is also under pressure, is admitted; this gas mixes with the air, which is still flowing in, and forms the explosive mixture.

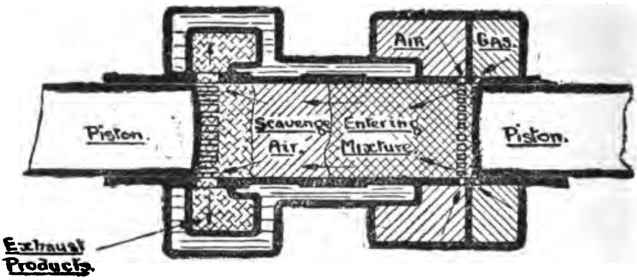


Fig. 31.—Oechelhauser Engine. Exhaust, Scavenging and Admission Period.

End of Admission and Exhaust.—After passing the dead centres, the pistons return and the gas ports are closed first, then the air ports, and, after a further short interval, the exhaust ports.

Compression.—The movement of the two pistons towards one another compresses the mixture until they reach the positions shown in dotted lines, when the gas is ignited, the working stroke follows, and the above cycle of operations is repeated.

At the beginning of the compression stroke, when all the ports have just been closed, the contents of the cylinder may be regarded as roughly divided into three portions :—

(1) At the exhaust end a quantity of scavenging air mixed with a small residue of the product of combustion from the previous explosion.

(2) An intermediate mixture of air and gas.

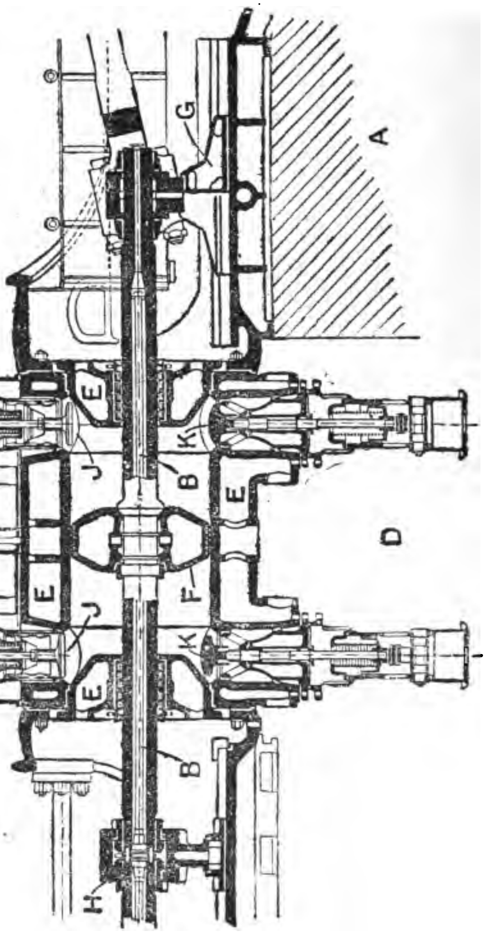
(3) A quantity of air admitted after the gas ports were closed.

It will be seen that the placing of admission and exhaust at opposite ends of the cylinder and the very long cylinder enable the scavenging air to clear out the products of combustion from the previous working stroke without mixing with them to any extent.

The scavenging air referred to under (1) above serves as a kind of diaphragm or wall separating the exhaust gases and the fresh mixture, and thus tends to prevent any of the mixture escaping unburnt through the exhaust ports. This action is sometimes referred to as stratification, and is illustrated in fig. 31.

M.A.N. Tandem Double-acting Engine.—Although the theoretical advantages of large gas engines from the point of view of economy are well known in this country, especially when using blast-furnace or coke-oven gas, yet very slow progress has been made in their use as compared with the progress which has been made on the Continent, particularly in Belgium and Germany. A Continental example will now be described of a large tandem double-acting four-stroke engine made by the Machinenfabrik - Augsburg - Nürnberg, Aktien - Geselleschaft, known in England by the contraction M.A.N.

Fig. 32 shows a sectional elevation through one cylinder, the crank shaft (not shown) being arranged on the right and a similar cylinder (also not shown) on the left, its piston being connected to the hollow piston-rod B. Both ends of each cylinder are closed, and both sides of the pistons receive power impulses. The two cylinders work together in such a way that every stroke has one power impulse, there being thus



A. Concrete Foundation.
B. Piston-rod.
D. Pit for Exhaust Valve Gear.
E. Wate Jackets.
F. Piston.
G. Crossheads.
H. Slide for Supporting Pistons.
J. Inlet Valves.
K. Exhaust Valves.

Fig. 32.—M.A.N. Tandem Double-acting Engine.

four working strokes in the complete cycle of two revolutions, one stroke for each end of each cylinder. The sequence of operations is illustrated in the following table :—

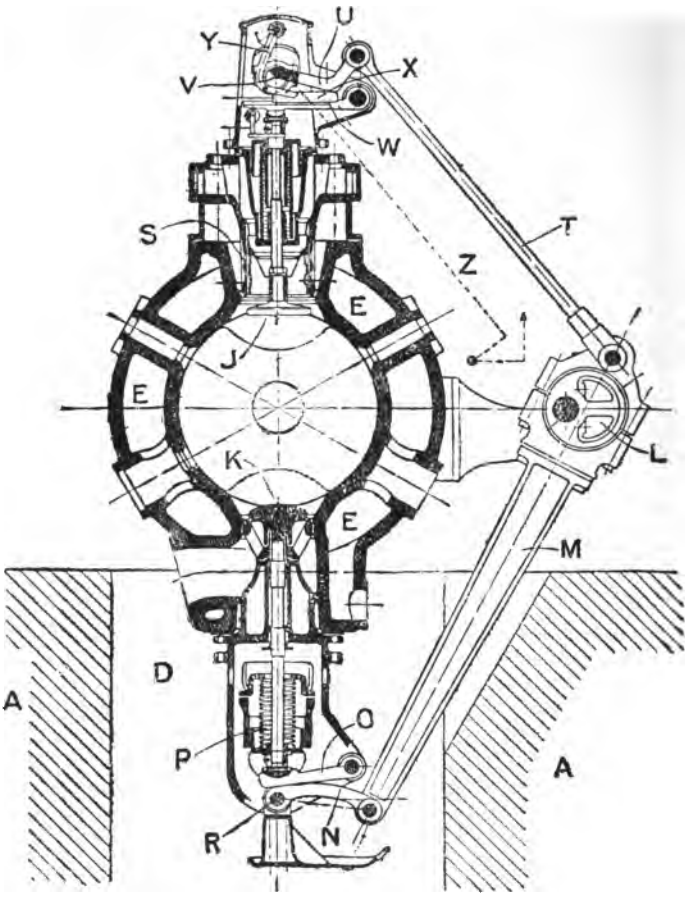
		BACK CYLINDER.		FRONT CYLINDER.	
		Front End.	Back End.	Front End.	Back End
First Revolution.	Forward stroke.	Suction.	Compression.	Working.	Exhaust.
	Return stroke.	Compression.	Working.	Exhaust.	Suction.
Second Revolution.	Forward stroke.	Working.	Exhaust.	Suction.	Compression.
	Return stroke.	Exhaust.	Suction.	Compression.	Working.

These tandem engines are made in sizes developing up to 3,000 H.P.

The framework of the engine consists of a massive box casting, which is bedded down on to a concrete foundation A, the cylinders being arranged over a pit D, so that the exhaust valve stems are below the floor level.

The body of each cylinder, the cylinder covers and stuffing-boxes, and the valve cages and seatings, are furnished with large water-jackets E. The piston-rods B and the pistons F are hollow, and have water circulating through them continuously under a pressure of from 45 to 65 lbs. per square inch, this pressure being required on account of their reciprocating movements and the comparatively small supply pipes. This provision for cooling is very important, in view of the very large size of these cylinders—viz., 4 to 5 feet in diameter.

The weight of the pistons and rods is entirely taken by the crosshead G, the slide H between the two



A. Concrete Foundation.
D. Pit for Exhaust Valve Gear.
E. Water Jackets.
J. Inlet Valves.
K. Exhaust Valves.
L. Eccentric.
M. Eccentric-rod.
N. Rocking Lever.
P. Exhaust Valve Spring.
S. Air Valve.
T. Inlet Operating-rod.
U, W. Inlet Operating Lever.
X. Adjustable Piece.
Y, Z. Connections to Governor.

Fig. 33.—M.A.N. Valve Gear.

cylinders, and a further slide (not shown) on the extreme left of the engine, so that the pistons float in their cylinders.

The inlet valves J (on top) and the exhaust valves K (below) are operated by a very simple gear, in which one eccentric only is employed and no cams. This gear is shown in fig. 33, which represents a section through the valves at one end of a cylinder. The eccentric L on the half-speed shaft reciprocates the eccentric-rod M, which is connected at its lower end to a rocking lever N. This lever lifts the exhaust valve K through the medium of a pivoted lever O, which engages the lower end of the valve stem. The valve is, as usual, lowered by a spring P. Although the rocking lever N reciprocates continually, it only lifts the valve when it is at the upper part of its movement. During the other part of its movement the circular end of the lever, which is concentric with the pivot R, merely rubs against the lever O without lifting it. The lever N is shown when just about to lift the valve.

The inlet valve J and the sliding sleeve or hollow cylindrical air valve S are rigidly connected, and are operated by rolling levers worked by a rod T from the eccentric L. The rod T oscillates the bent lever U, which is pivoted at V and depresses the rocking lever W when required through the medium of an adjustable piece X. The lever W acts on the end of the valve stem, and depresses the combined valves, so as to open them when required. The position of the adjustable piece X determines the amount of opening of the valves. The maximum opening is given when the piece is in the position shown, the opening being reduced by moving it towards the left. This adjustment is effected automatically by a bent lever Y connected to the governor, the connections being indicated by the dotted lines Z.

The composition of the mixture is practically constant once the valves have been set for the most efficient combustion according to the kind of gas

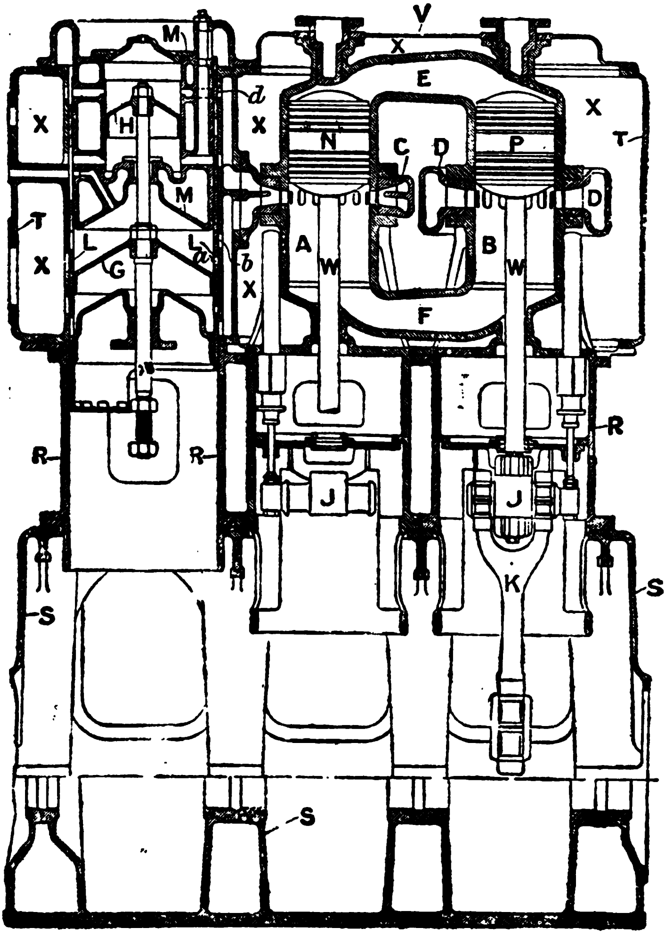


Fig. 34.—Mather & Platt "Duplex" Engine.

used. If the gas changes, the ratio of air to gas can be readily altered by hand by turning the air slide valves while the engine is running.

For starting the engine compressed air is used, the crank shaft being first turned into a suitable position by manual barring gear in the smaller sizes, or by an electric barring gear in engines from 500 H.P. upwards. Compressed air at 300 lbs. per square inch pressure is then admitted to the cylinder through starting valves, worked at first by hand and then by the half-speed or lay shaft by means of a cam. A non-return valve is fitted at the point where the compressed air is admitted to the cylinder.

Fig. 34.

A, B.	Cylinders.	N, P.	Power Pistons.
C.	Inlet Belt.	R.	Cylinder Supports.
D.	Exhaust Belt.	S.	Base Plate Casting.
E, F.	Passages connecting Cylinders.	T.	Water-jacket Casing.
G.	Air Pump Piston.	V.	Water-jacket Cover.
H.	Gas Pump Piston.	W.	Piston-rods.
J.	Crossheads.	X.	Water Spaces.
K.	Connecting-rods.	*a*, *b*.	Air Ports.
L.	Sleeve Valve.	*d*.	Gas Ports.
M.	Gas Pump Cylinder.		

Mather & Platt "Duplex" Engine.—This engine is of British design and manufacture, and contains many novel features. It is double-acting, and works on the two-stroke cycle, and the cylinders and air and gas pumps are vertical, so that very little floor space is occupied in comparison with engines of the horizontal type.

Fig. 34 shows a section through the two cylinders and their associated air and gas pumps. The essential feature of the design is the formation of a pair of double-acting cylinders A, B from two U-shaped castings, the upper inverted U casting being bolted to the lower U casting with the inlet belt C and the exhaust belt D between them. Through the pipes E, F at top and bottom there is intercommunication between the two upper ends and the two lower ends respectively of the Duplex cylinders. A single-combustion chamber is thus formed above the pistons and another below. The exhaust always takes place through the central ports in the right-hand cylinder B, and the scavenging air and the gas are admitted through the central ports in the left-hand cylinder A. On the left of the figure is shown the air and gas pumps. The air pump piston G is of considerably larger diameter than the working pistons, and is fixed to the same rod as the upper and smaller gas pump piston H. The two working pistons N, P and the air and gas pump pistons G, H are connected to a three-throw crank shaft through crossheads J and connecting-rods K. The cranks for the working cylinders are arranged at an angle of 15° to one another, the exhaust or right-hand crank leading so that the exhaust ports are always opened slightly before the inlet ports, and also close earlier. The air pump piston G works in a cylindrical sleeve valve L, which is given a vertical reciprocating motion from two eccentrics. The cylinder in which the upper gas pump piston H works consists of a casting M, which is supported at its upper end and also forms the top of the lower air cylinder. The sleeve valve projects up outside this gas cylinder, and thereby controls the inlet and outlet of gas to and from the gas cylinder, as well as controlling the flow from and to the air cylinder.

The sequence of operations during the cycle will now be described, the upper ends of the cylinders being considered.

Exhaust Opens.—Both main pistons N, P are moving downwards with exhaust piston P ahead of or further down than the other, and just uncovering the exhaust ports. Both pistons then continue their downward movement.

Scavenge Inlet Opens.—After a small further movement the inlet piston N uncovers the inlet ports, and air flows from the upper end of the air cylinder through the ports *a* in the sleeve L, the ports *b* in the air cylinder walls and the inlet belt C; this air scavenges the cylinders or clears out the exhaust gases. The air pump delivers air at a pressure of about 4 lbs. per square inch.

Gas Inlet Opens.—The sleeve next opens the ports *d*, allowing gas to pass from the upper end of the gas cylinder and mix with the air to form the fresh charge.

Exhaust Closes.—The exhaust piston P moving upwards now closes the exhaust ports, and

Inlet closes shortly afterwards when inlet piston N reaches inlet belt C, the gas supply having been cut off slightly before, so that air only is left in the passages.

Compression.—Both pistons N, P move upwards and compress the mixture into the connecting passage E.

Working Stroke.—Piston P reaches the top of its stroke slightly before piston N. Ignition takes place about this time, and the two pistons move downwards until piston P uncovers the exhaust ports D, and the cycle is then repeated.

The scavenging or first-admitted air clears out the exhaust products, and the air and gas mixture follows the scavenging air.

The cycle of operations for the lower ends of the cylinders is identical, the lower ends of the air and gas cylinders in this case supplying air and gas respectively.

When the duplex cylinder castings and the pumps have been set upon their stools R, upon the crank casing or base plate casting S, a light casting T is built around them and covered in at the top by a cover

V, which is thin enough to be slightly flexible. This forms a tank, which is filled with water for the cooling of the parts subjected to the heat of combustion and to the heat of the burnt products. These heated parts are free to expand and contract independently of the tank casing, which is thus not subjected to any working stress. For instance, the cylinders can expand and contract vertically, and the flexible cover prevents any stress from being communicated to the casing.

These engines may be built so as to develop very high powers. As an example, the dimensions are given below of a 6,000 brake-horse-power twin engine in which two of the above sets are combined so as to form a single engine with a six-throw crank shaft.

Diameter of cylinders,	36 inches.
Stroke of cylinders,	43 ,,
Speed,	140 revs. per min.
Diameter of flywheel,	12 feet 3 inches.
Weight of flywheel,	60 tons.
Floor space occupied by engine,	475 square feet.

CHAPTER VI.

PETROL ENGINES.

Introduction.—The term petrol engines is applied to engines in which the fuel used is easily vaporized without heat; practically the only fuels used are the lighter distillates of crude oil (commonly known as petrol in this country and as gasolene in America) and benzol, the latter being obtained as a bye-product in the manufacture of coal-gas. These fuels are described in Chap. III. The gas engines described in Chap. IV. can be adapted to use petrol by the provision of special vaporizing or carburetting devices.

Small country-house electric lighting plant, small water-pumping plant, and similar miscellaneous apparatus is sometimes driven by petrol engines, but the cost of petrol is too high at the present day to allow of its use for general power purposes, except when small powers only are required.

Petrol engines are, however, very simple and self-contained, very easily started without preparation, and are very reliable, and these advantages are often sufficient to outweigh the disadvantage of high running cost. Small petrol engines are sometimes used as auxiliaries to large gas or oil engines for compressing air for starting purposes.

The above remarks apply to stationary engines intended for general power production. In its own sphere the petrol engine has no rival. It is almost exclusively used on motor cars and motor cycles; it is the only kind of engine used on aeroplanes, and it is also used largely on small launches and fast motor boats.

There are two main reasons for the superiority of the petrol engine for such purposes. In the first place, a petrol engine, with its carburetter, ignition devices, and petrol tank, forms a complete power unit. If this unit be compared with, for instance, a gas engine and its appurtenances, including a gas-producing plant, it will be seen to be necessarily much lighter, since a gas engine cannot be far from a gas works or gas-producing plant. In the second place, the petrol engine can be run at very high speeds, so that a great deal of power can be developed for a given weight of engine and accessories. That is, the ratio of power to weight is very high. This is a most important consideration for a motor car, aeroplane, or fast motor-boat engine. Compare it, for instance, with an oil-injection engine; the speed of running is chiefly limited by the difficulty of injecting and also properly atomizing the oil injected into the cylinder, whereas the petrol engine takes into the cylinders a mixture of air and petrol vapour, which can be very easily formed, owing to the great ease with which petrol can be vaporized.

Petrol engines, as developed for use on motor cars, etc., are of very special and distinctive design. They can be run at a speed of 3,000 revolutions per minute or more, although such a speed is not advisable for continuous periods. This high speed necessitates the use of very light and strong material for the moving parts, such as the connecting-rod, and also requires great attention to be given to balancing, so as to avoid vibration.

The majority of petrol engines work on the four-stroke cycle. There are, however, one or two designs working on the two-stroke cycle; these will be described later. The valve-operating gear in commonest use employs cams as in gas and oil engines, the only extensively used alternative being the sleeve-valve engine introduced in the first instance by the Daimler Motor Company.

Petrol engines are both air and water-cooled, the air-cooled engines being used mostly on motor cycles and in rotary cylinder aeroplane engines, such as the Gnome; water-cooled engines are almost universally employed on motor cars.

The cylinders of petrol engines are small when compared with engines such as we have been considering in previous chapters.

Owing to the high speed at which petrol engines run, very careful provision has to be made for lubrication. Broadly, there are two systems in use for multi-cylinder engines—viz., forced and trough. In the former oil drawn from the sump or lower part of the crank case is forced under pressure by a pump worked by the engine through passages or pipes to the main crank-shaft bearings, and thence through holes drilled in the crank shaft to the big connecting-rod bearings. The small end bearings, the cylinder walls, and the cams, cam-shaft bearings, and tappets are generally lubricated by the surplus oil splashed out of the bearings. The Star engine, to be described shortly, is an example of this system.

In the trough system, dippers on the lower ends of the connecting-rod dip into troughs containing oil kept at a constant level. The troughs are supplied by a pump, and the excess overflows into the sump. All the parts are thus lubricated by splash, and the amount of oil thrown about can be regulated to some extent by varying the oil level in the troughs or the lengths of the dippers. The Daimler engine, to be described later, employs this system.

Rudge - Whitworth Motor Cycle Engine. — An example of a high-speed single-cylinder petrol engine

Fig. 35.

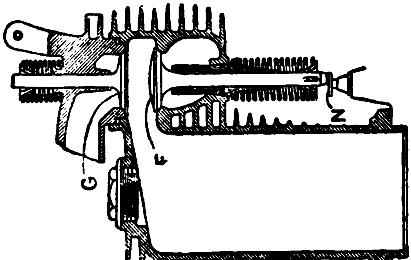


Fig. 36.

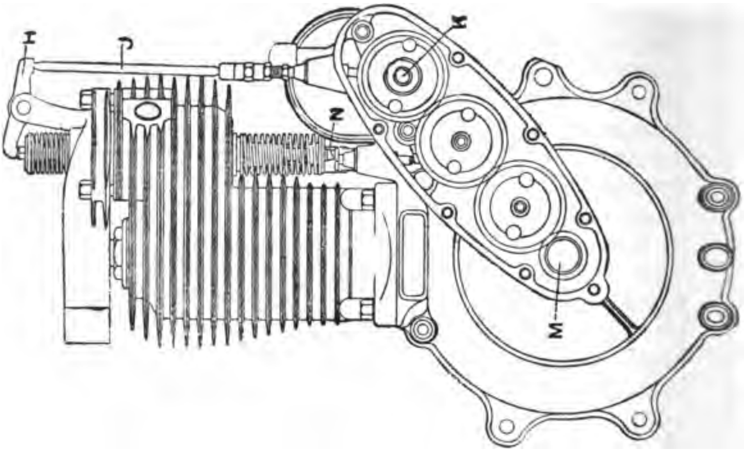
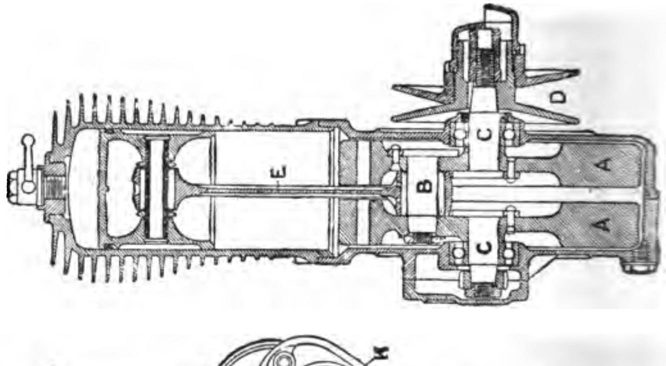


Fig. 37.



Rudge-Whitworth Motor-Cycle Engine.

for a motor cycle is illustrated in figs. 35, 36, and 37, the dimensions of the engine being—diameter 85 millimetres, stroke 88 mm., or expressed in English units, $3\frac{11}{32} \times 3\frac{15}{32}$ inches. This engine is air-cooled; the movement of the vehicle through the air ensures a satisfactory cooling effect, sufficient heat being radiated by means of ribs or fins cast on the outside of the cylinder. Fig. 36 shows an outside view of the engine with the cover of the train of gear wheels driving the cam shaft removed. Fig. 35 shows a similar sectional view of the cylinder only, and fig. 37 shows a sectional view of the cylinder, crank case, and flywheels.

	Figs. 35, 36, and 37.
A.	Flywheels.
B.	Crank Pin.
C.	Crank Shaft.
D.	Driving-belt Pulley.
E.	Connecting-rod.
F.	Exhaust Valve.
G.	Inlet Valve.
H.	Inlet Valve Rocking Lever.
J.	Inlet Valve Push-rod.
K.	Cam Shaft.
M.	Crank Shaft.
N.	Flat Disc on Tappet.

All the parts of this engine are completely enclosed, including the flywheels A, which are built up so as to form part of the crank shaft M.

The two flywheels are rigidly connected to one another by the crank pin B, and each is fitted with a short spindle C carried by ball bearings in the crank casing. One of the spindles projects through the casing and carries the driving belt pulley D. Both flywheels are externally of circular shape, but the part of the rim opposite to the crank pin B is deeper and heavier than the rest of the rim, so as to balance the weight of the crank pin and the end of the connecting-rod E.

This engine is somewhat different from most designs in that roller bearings are provided at both ends of the connecting-rod.

The exhaust valve F and the inlet valve G are placed one above the other, the inlet valve being operated through the medium of an overhead rocking lever H and a push-rod J, which is operated from a cam on the cam shaft K; the exhaust valve G is operated from the cam through an interposed pivoted lever. The cam shaft is driven from the crank shaft M at half-speed through a train of gear wheels, the lowest of which dips in oil.

This engine, like many motor-cycle engines, relies upon splash lubrication. A hand pump is fitted on the cycle by means of which oil is occasionally injected into the crank case, this oil being thrown about by the flywheels to the various bearings and cylinder walls. As a means of lubricating the parts, this method seems to be quite effective, but an excess of oil is splashed on to the cylinder walls, works above the piston, and becomes carbonized by the heat of combustion, necessitating frequent cleaning of the top of the piston and the interior of the combustion chamber. All engines, of course, require cleaning for the purpose of removing carbon deposit, but motor-cycle engines more often than other engines. The power is conveyed to the road wheel from the crank shaft by means of a V belt and an expanding pulley D. It will be seen that the exhaust valve stem is not in line with the tappet, but engages towards the edge of a flat disc N. The object of this is to reduce wear, since the disc will work round and round, and the wear thus be distributed all over its surface.

Most motor-cycle engines are at the present day provided with a clutch or with belt disconnecting

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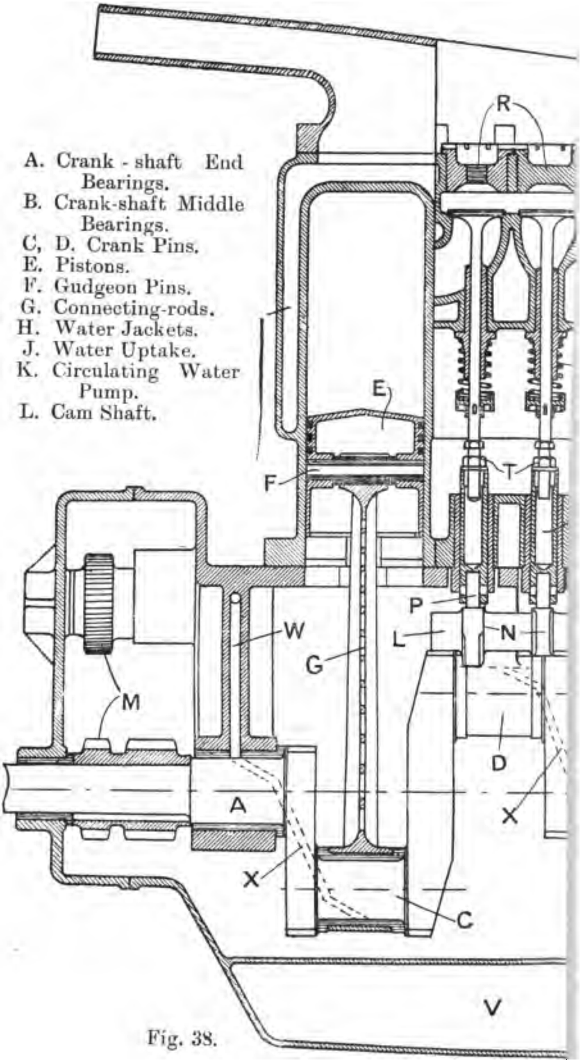
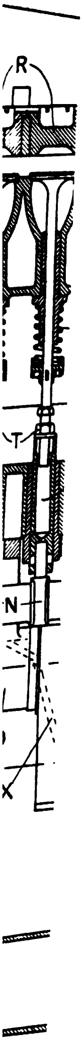


A. Crank-shaft End Bearings.
B. Crank-shaft Middle Bearings.
C, D. Crank Pins.
E. Pistons.
F. Gudgeon Pins.
G. Connecting-rods.
H. Water Jackets.
J. Water Uptake.
K. Circulating Water Pump.
L. Cam Shaft.

Fig. 38.



gear, so that the engine can turn independently of the driving wheel. The crank shaft is turned for starting by pedal gearing operating through a free wheel or by a kick starter. In the Rudge machine there is a pedal gear, and an exhaust valve lifter is provided to make starting easier. A small lever, operated by a Bowden wire, lifts the exhaust valve stem slightly when starting, so as to reduce the compression.

Star Four-cylinder Engine.—The great majority of motor-car engines have four cylinders. An example of a modern high-speed engine of medium power, made by the Star Engineering Company, is shown in figs. 38 and 39. The cylinders of this engine have a bore of 80 mm. and a stroke of 150 mm., the stroke being rather longer than is usual with cylinders 80 mm. in diameter, or, as it is commonly expressed, the stroke-bore ratio is high. Fig. 38 shows the first cylinder from the left and the valve gearing of the second cylinder in section, the two right-hand cylinders being shown in outside elevation. Fig. 39 shows a transverse section through one of the cylinders, the connecting-rod of the next cylinder being also seen.

The crank shaft is supported in two end bearings A and a middle bearing B, this being the bearing arrangement in most common use, although five-bearing and two-bearing crank shafts are largely used. The cranks all lie in the same plane, the two end cranks C being coincident and the two middle cranks D making an angle of 180° with the end cranks.

The two end pistons E move up and down together, and the two middle pistons also move up and down together, but the end pistons are moving up while the inner ones are moving down and *vice versâ*; this ensures a satisfactory balance of the reciprocating parts, which is very essential for the comfort of the occupants of the car, since the frame of the vehicle forms a very light foundation, and would not absorb shocks due to want of balance. In connection with this question of balance, it should be noted that the pistons are made exceptionally light, the weight of each piston complete with hollow gudgeon pin F and rings being about 1 lb. 9 ozs. The webs of the connecting-rod G are drilled, also with the object of reducing weight.

The cylinders are cast in pairs, the two forward cylinders, their water-jackets H, and valve spaces being in one complete casting, while the two rear cylinders and similar parts form a separate casting. The two cylinder castings are bolted to a two-part crank casing cast in aluminium, the two parts of which are divided on a plane containing the axis of the crank shaft. The crank-shaft bearings A, B are bolted up to the upper part. The water spaces H surround all the parts of the cylinder exposed to the hot gases and also the valve spaces. The top of the water spaces in the main casting is covered by the water uptake J. The water circulates upwards through the cylinder jackets and passes to the top of the radiator on the front of the car. It is cooled when passing downwards through the radiator, and then is again conducted to the lower ends of the cylinder jackets. A rotary pump K circulates the water continuously. The cam shaft L is driven at half the speed of the crank shaft by a silent chain engaging the sprockets M, and the cams N bear against the rollers P on the lower ends of the tappets Q. The sparking plugs for effecting ignition are screwed in through the inlet-valve caps R. The working parts of the engine are completely enclosed in the crank casing. The valve springs S and the adjustable tappets (that is, the screw-adjusting gear T between the ends of the valve stems and the tappets for taking up wear) are enclosed by detachable cover-plates.

The crank or big ends of the connecting-rods are provided with divided white-metal bearings, so that adjustment for wear can readily be made.

The engine is placed with the crank shaft longitudinally in the frame of the car, the left-hand end being towards the front, and the end of the crank shaft is provided with suitable teeth for the engagement of the starting handle; the drive to the clutch, gear-box, and rear axle is taken from the rear end of the crank shaft. A magneto for ignition is mounted on a side extension of the crank casing, and is driven by a silent chain from the crank shaft, this chain and also that for driving the cam shaft being completely enclosed.

It will be seen from fig. 39 that the axes of the cylinders are slightly out of line with the axis of the crank shaft, or, as it is expressed by the French, the cylinders are *des axe*.

The lubrication system is of the forced type referred to previously. A pump drains oil from the sump V, and delivers it under pressure through passages W to the three main bearings, from which it passes through drilled passages in the crank shaft (shown diagrammatically in dotted lines) to the big end bearings. The surplus oil is thrown about, and after lubricating the various other working parts, returns to the sump.

Since there is an explosion on alternate down strokes of each cylinder, it follows that the turning impulses on the crank shaft occur at intervals of 180° of crank-shaft movement. The cylinders fire in the order 1, 2, 4, 3, or alternatively in the order 1, 3, 4, 2. In the case of a six-cylinder engine the impulses occur at intervals of 120° of crank-shaft movement, and in the case of an eight-cylinder V engine with the two sets of cylinders at 90° to one another, the firing impulses occur at intervals of 90°.

Sunbeam Aircraft V Engine.—V engines are constructed with the axes of two cylinders at 90°, or at some lesser angle to one another, and with both connecting-rods working on the same crank pin. In some designs the big end of one of the connecting-rods is forked, the big end of the other rod being disposed between the forks of the first rod, while in other designs the cylinders are placed slightly out of line, and the big ends are arranged side by side on the same crank pin.

V engines with two cylinders have been used occasionally on motor cars, and are often employed on motor cycles. Eight-cylinder V engines have been used on some De Dion motor cars for a number of years, and eight-cylinder and twelve-cylinder engines have more recently been introduced in American cars. They have also been used in motor boats and on aeroplanes.

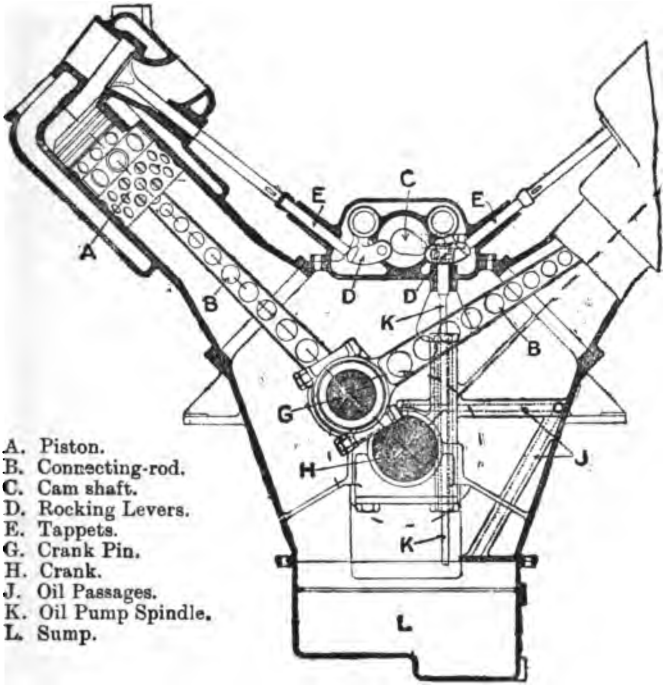
Fig. 40 shows a transverse section of one pair of cylinders on a Sunbeam aircraft engine having eight cylinders, certain parts being omitted. This engine may be looked upon as two four-cylinder engines with their axes at 90° to one another, and with a common crank shaft having the usual arrangement of cranks described previously in connection with the Star engine.

The pistons A and connecting-rods B are both very light, being made of steel and drilled freely. The big ends of each pair are arranged side by side on the same crank pin.

Only one half-speed cam shaft C is employed. Each cam operates two valves, one on each cylinder, through pivoted rocking levers D, which engage the usual tappets E. The valves are, as usual, returned by springs (not shown on the drawing).

The lubrication is of the forced type, similar in principle to that described in connection with the

Star engine, but the oil is delivered to the bearings at a much higher pressure, in view of the very severe working conditions. A gear-wheel lubricating pump is placed in the sump, and is driven from the vertical spindle K, which in turn is driven from the cam shaft.



A. Piston.
B. Connecting-rod.
C. Cam shaft.
D. Rocking Levers.
E. Tappets.
G. Crank Pin.
H. Crank.
J. Oil Passages.
K. Oil Pump Spindle.
L. Sump.

Fig. 40.—Sunbeam Aircraft V Engine.

This pump draws oil from a tank, and forces it under pressure to the cam-shaft case, and the main bearings, from which it passes to the big end bearings through the hollow crank shaft. The surplus oil which collects in the sump is returned by a secondary pump to the oil tank, so that it is not exposed to the heat of the crank case for any length of time. A pressure gauge is placed on the oil-delivery pipe, and the oil pressure must be maintained above 35 lbs. per square inch. This pressure can only be maintained if the oil is prevented from becoming overheated (*i.e.*, above 60° Centigrade). An oil cooler may be necessary.

Six-cylinder water-cooled engines and V engines having eight and twelve cylinders are rapidly superseding the rotary-cylinder air-cooled engines of the Gnome type for use on aircraft. Although they are heavier than the rotary engines, their consumption of fuel and oil is so much less that the total weight of engine, fuel, and oil for a flight of anything more than two or three hours is less in the fixed cylinder engine than in the other type.

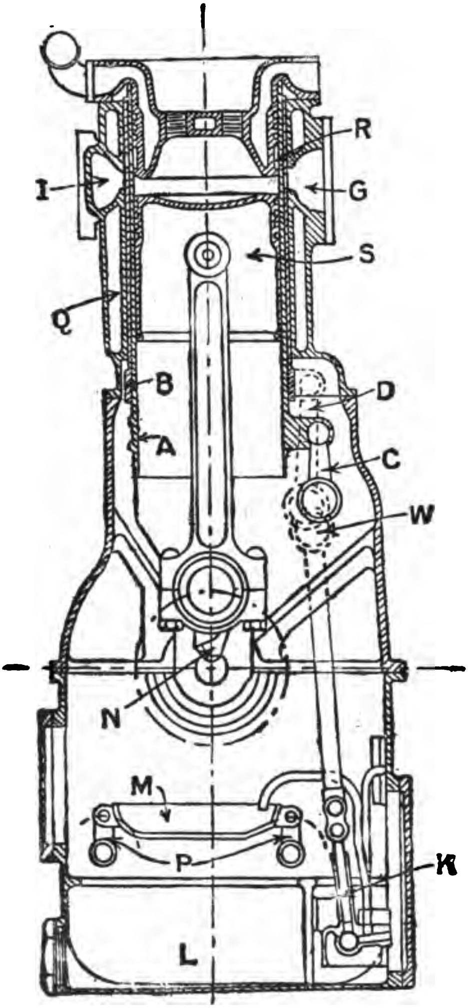
The Sunbeam Motor Company manufacture eight-cylinder aircraft engines, as described above, and also twelve-cylinder engines, as illustrated on the frontispiece. The cylinders of both of the engines illustrated are 90 mm. in diameter, and the stroke is 150 mm. The twelve-cylinder engine will now be described.

The frontispiece shows the six cylinders on one side of the engine; the other side is substantially the same, and the two sets of cylinders are inclined at 60° to one another. The cylinders are cast in groups of three, and each group is provided with its own carburetter. The mixture from each carburetter passes through a forked induction pipe heated by a water-jacket, and is then led between the cylinders to the inlet valves. A centrifugal pump shown on the left circulates the cooling water. Twelve water outlet pipes are provided, one above each cylinder. The twelve cylinders each exhaust by a separate pipe into an exhaust pipe of large diameter arranged centrally, and shown above the cylinders. Two six-cylinder magnetos are driven from a transverse shaft, one of these magnetos being shown on the left. The crank shaft is carried in seven bearings, two at each end, the other five being arranged as intermediate bearings, one between each throw. A flexible driving joint for a wireless installation is shown on the extreme left of the figure. On the right is shown the coupling for the hub of the propeller, this coupling being carried by a short shaft arranged above the crank shaft, and rotating at half crank-shaft speed.

The normal speed of the engine is 2,000 revolutions per minute, giving a propeller speed of 1,000 revolutions per minute. At this speed the eight-cylinder engine develops 150 H.P. and the twelve-cylinder 225 H.P. The approximate weight of the twelve-cylinder engine complete, not including the radiator, is 900 lbs.

Knight Sleeve Valve Engine.—The Knight sleeve valve engine was the result of the efforts of Mr. Charles Y. Knight, an American, to find a satisfactory substitute for the noisy poppet-valve motors. In 1908, Mr. Knight visited England and interested the Daimler Company in his engine, with the result that it was manufactured by them for sale the following year. The unusually silent running of the Knight engine also brought about much improvement in the poppet-valve engine, since it stimulated the makers to fresh efforts to improve and silence their engines against such a formidable competitor. The sleeve-valve engine is now used exclusively by the Daimler Company on their ordinary cars, motor 'buses, and lorries.

The essential and characteristic feature of the Knight engine, of which a transverse section of one cylinder is given in fig. 41, is the employment of two concentric sleeves A, B, reciprocated independ-



A. Inner Sleeve.
B. Outer Sleeve.
C, D. Connecting-rods for Sleeves.
G. Exhaust Port.
I. Inlet Port.
K. Oil Pump.
L. Sump.
M. Oil Troughs.
N. Dippers on Big Ends.
P. Supporting Links for Oil Troughs.
Q. Cylinder Wall.
R. Packing Ring.
S. Piston.
W. Half-speed Eccentric Shaft.

Fig. 41.—Knight Sleeve Valve Engine.

ently, and interposed between the cylinder Q and the piston S. The use of two sleeves ensures rapid opening and closing of the exhaust and inlet ports G, I in conjunction with a sufficient area of opening.

The cycle of operations is the usual four-stroke. The inner sleeve A and the outer sleeve B are moved up and down by short connecting-rods C, D worked by the half-speed eccentric shaft W. These sleeves are of cast iron, and are quite thin. In a certain recent design of engine, having four cylinders 90 mm. diameter by 130 mm. stroke, the thickness of the inner sleeve is 3½ mm., and that of the outer sleeve is 2¾ mm. The stroke of each sleeve is 22 mm. The inlet port I on one side and exhaust port G on the other side, each extend nearly half-way round the circumference of the cylinder. The sleeves are provided with corresponding ports H and F, shown also in figs. 42 and 43. When the motion of the sleeves brings the two sleeve ports H into line with the cylinder port I, the mixture of air and petrol vapour from the carburetter enters the cylinder freely. The sleeves are shown in this position in fig. 42. Similarly,

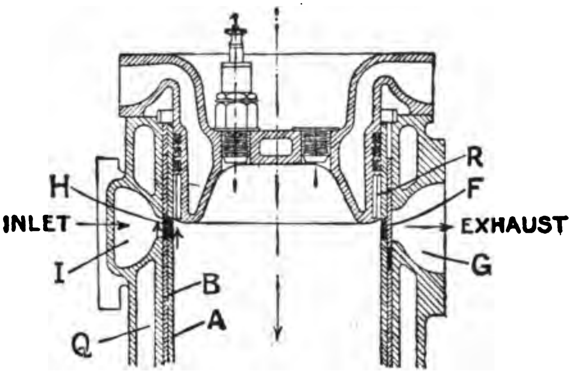


Fig. 42.—Inlet Ports Open.

when the two sleeve exhaust ports F register with the cylinder exhaust port G, the products of combustion can be expelled. Fig. 43 shows the sleeves full open to exhaust.

Examination of the drawings will show that the sleeves project upwards into a recess formed between the cylinder walls and the depending cylinder head. Leakage of gas is prevented by a broad junk ring R at the bottom of the cylinder head and three other rings above the junk ring.

The cylinder body and the detachable head are both water-jacketed.

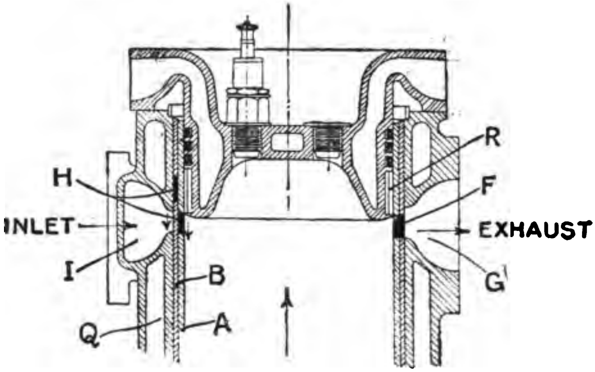


Fig. 43.—Exhaust Ports Open.

The operating rods for the sleeves are placed at one side only, and obviously tend to tilt the sleeves. It is found in practice that no harm results from this arrangement in ordinary use. In one design of Knight engine for racing the sleeves were each operated by two connecting-rods on opposite sides, two cam shafts being employed.

This sleeve-valve engine affords a good example of a lubricating system of the trough type. The oil pump K of the plunger type is worked from the eccentric shaft W. Oil drawn from the sump L is delivered to movable troughs M under the connecting-rods, and also to fixed troughs (not shown) along the inside of the crank case, from which it flows to the five main crank-shaft bearings. Dippers N on the ends of the connecting-rods dip into the oil in the movable troughs M. The big ends are lubricated in this way, and the oil splashed up serves to lubricate the sleeves, pistons, gudgeon pins, eccentric-shaft bearings, and rods. The movable troughs are carried by pivoted links P connected to the throttle control, so that the oil level is raised or lowered according to the opening of the throttle valve. The amount of oil splashed up is thus proportioned to the power developed.

Scott Two-stroke Cycle Engine.—Two-stroke petrol engines are used on only one make of motor car, but have been used rather more extensively on motor cycles and in small-powered motor boats. The Scott two-cylinder two-stroke motor cycle engine is of unique design, and has been very successful. The engine forms a part of the frame, and is inclined at about 45°.

It will be seen by reference to figs. 44 and 45 that the number of parts is, as usual, less than in four-stroke engines. The crank shaft A is carried in two roller bearings B, and is provided with two overhung cranks C at an angle of 180° to one another, the big ends also being provided with roller bearings. The crank cases serve as the pumps or compression chambers. The fiywheel D is arranged between the cylinders, and the power is transmitted by means of two chain sprocket wheels E.

The piston F, when nearing the lower end of its stroke, uncovers the exhaust port G, and the delivery end of the transfer passage H, J, the mixture compressed in the crank case being then transferred to

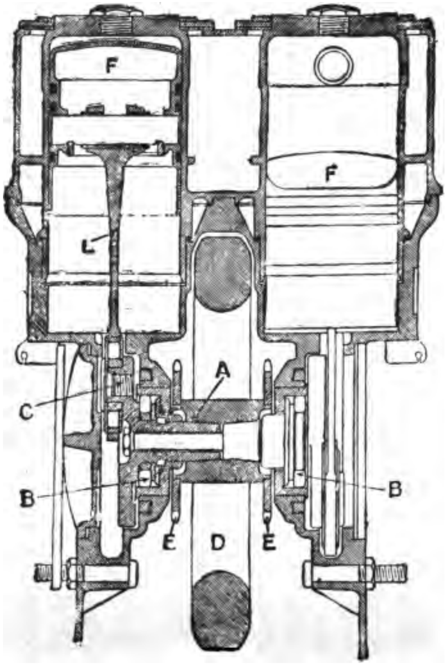


Fig. 44.

A. Crank Shaft.
B. Crank-shaft Roller Bearings.
C. Crank Pins.
D. Flywheel.
E. Chain Sprockets.
F. Pistons.
G. Exhaust Port.
H, J. Transfer Passage.
K. Inlet Passage to Crank Case.
L. Connecting-rod.

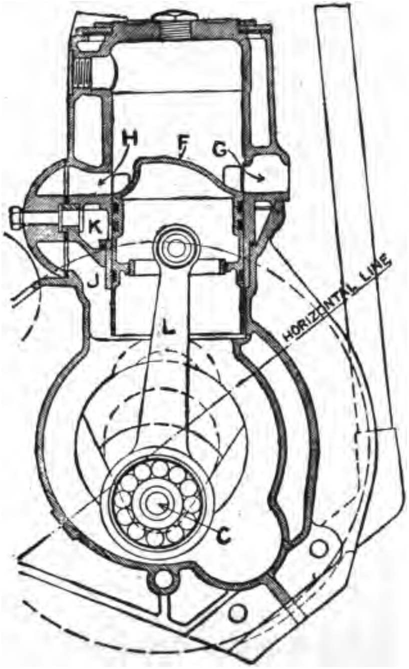


Fig. 45.

Scott Two-stroke Cycle Engine.

the cylinder through the transfer passage. When the piston has moved upwards sufficiently, the inlet port K is uncovered, and a fresh supply of mixture enters the crank chamber, and is compressed on the next down stroke.

A two-cylinder two-stroke engine gives two working strokes in every revolution, and the torque is, therefore, as even as that of a four-cylinder four-stroke engine. The slightly greater fuel consumption is of less importance in a motor cycle than in the much heavier car.

The method of working will be readily followed if reference is made to the description in Chap. II. of the two-stroke cycle.

Valve Timing.—The petrol engine, with few exceptions, is essentially a high-speed engine, and this characteristic necessitates special and careful valve adjustment so as to get correct timing of the opening and closing points. Fig. 46 shows the valve timing for a Daimler sleeve-valve engine, this diagram being typical of all high-speed petrol engines.

The diagram shows the crank positions of a vertical engine when the different events in the cycle take place. The direction of rotation is indicated by the arrow A.

The exhaust valve opens when the crank is at A, 54° ahead of the lower dead centre. This ensures that the burnt gases have escaped sufficiently by the time the working stroke is complete, to prevent back pressure on the exhaust stroke.

The exhaust closes 15° late—that is, when the crank is at B, 15° past the dead centre; the inlet opens 10° late. The crank is thus moving through 5° while both inlet and exhaust are slightly open, or, as it is commonly expressed, an overlap of 5° is allowed. The inlet closes at D, 31° late.

The sole reason for this lag and lead of the different events of the cycle is the inertia of the gases. Take, for instance, the point D. During the suction stroke the piston moves so rapidly that the fuel and air mixture cannot follow it up, and there is, therefore, a partial vacuum in the cylinder. If the inlet were closed at the end of the stroke, the cylinder would be only partially filled. By closing the inlet later the mixture is given time to fill the cylinder, and a fuller charge is drawn in. Similarly, the exhaust closes late, to allow the exhaust gases time to escape. Their inertia when flowing out of the cylinder may

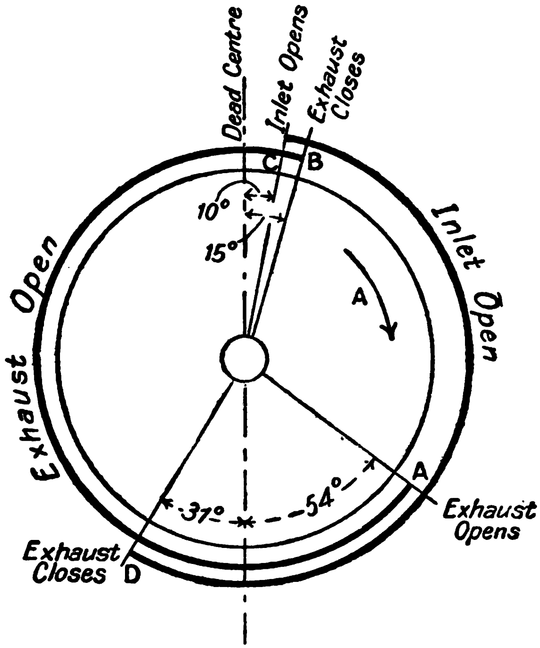


Fig. 46.—Valve Timing.

even create a partial vacuum, and thus facilitate the rapid entry of the fresh charge of mixture.

These above angles are given by way of example; they are varied somewhat in different engines. The subject of valve timing is intimately associated with diameter and lift of valves (in poppet-valve engines), and with the shape and dimensions of the exhaust and inlet pipes.

Carburation.—Carburetters for motor cars have received an enormous amount of attention from inventors and designers in recent years, and great improvements have been effected.

At one time surface carburetters were in serious competition with jet carburetters, but, at the present time, there is only one motor car constructed (the Lanchester) in which a surface carburetter is employed. In the surface carburetter the air required passes among a number of cotton wicks, which are kept saturated with petrol by reason of their lower ends dipping into a petrol receptacle. The air emerges strongly saturated with petrol vapour, and is then more or less diluted with pure air, according to the requirement of the engine. Surface carburetters have declined in popularity because of their bulk and their tendency to fractional vaporization—that is, the vaporization of the lighter constituents of the fuel first, leaving the heavier constituents behind, although the experience of the Lanchester designers shows that it is possible to remedy this last defect.

The jet carburetter is the only kind which it is proposed to consider in detail. In this type a spray of petrol is projected from a small jet or jets into the current of air flowing to the engine. In the case of stationary engines, in which the power demand is approximately constant, the construction of a satisfactory carburetter presents few difficulties, since it is easy to adjust the relative proportions of air and petrol to give the right mixture.

In the case of motor cars, the conditions are entirely different; a motor-car engine is required to run at speeds varying from a few hundred to some thousands of revolutions per minute, to exert a large or small torque or turning effort at either high or low speeds, or even to turn slowly and quietly without giving out any useful power; also to accelerate rapidly and start easily when cold without special preparation. A carburetter should further give economical running, should be simple and cheap, and should not require skilled adjustment. A carburetter which will automatically adjust itself to these extremely varied conditions requires to be very carefully designed. That the problem has not yet been finally solved is shown by the great variety of carburetters in use.

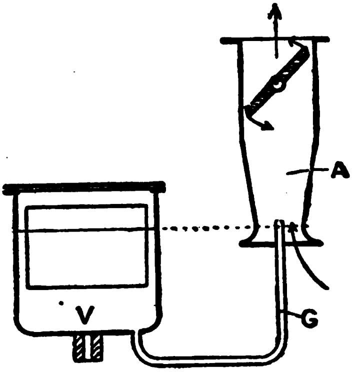


Fig. 47.—Simple Carburetter.

Most carburetters are intended to supply the engine with a mixture of air and petrol of constant strength at all speeds, but the average pressure in the cylinders (and consequently the torque or turning effort) is varied at any speed by throttling or regulating the quantity of this constant strength mixture admitted to the cylinders. The simplest form of "jet-in-tube" carburetter, shown diagrammatically in fig. 47, suffers from the defect that the mixture becomes richer the higher the engine speed, producing an excess of petrol at high speeds and a deficiency at low speeds. In some carburetters this tendency is neutralized by fitting additional jets and making the flow through these jets independent of the suction of the engine. In other carburetters the ratio $\frac{\text{petrol}}{\text{air}}$ is kept constant

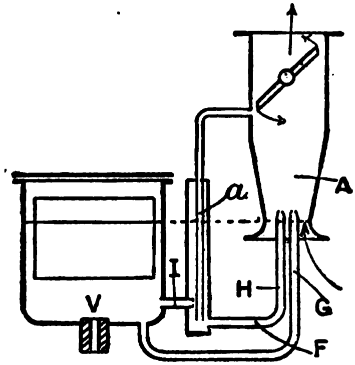
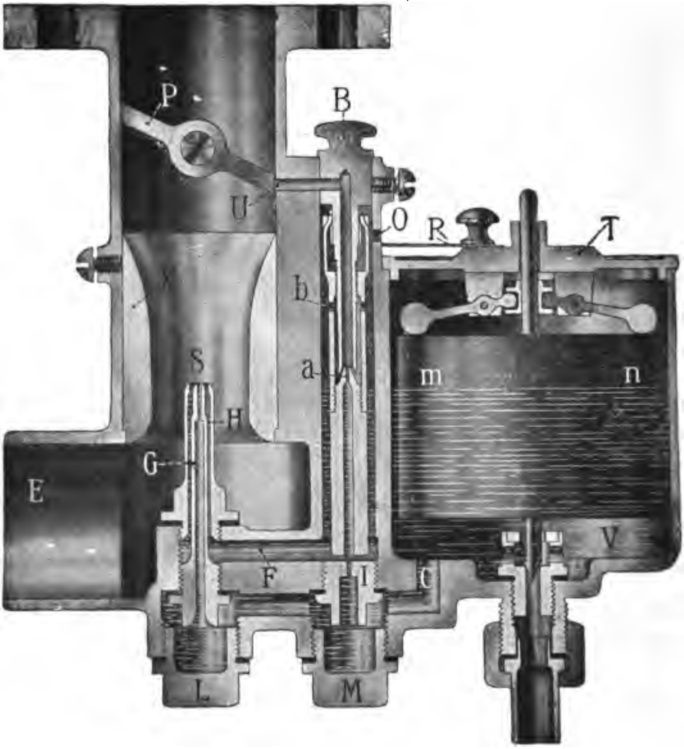


Fig. 48.—Zenith Carburetter.

at all speeds by regulating the size of the petrol opening or the air inlet or both, either by a connection to the throttle valve or by means of an independent moving part.

Zenith Carburetter.—The principle of operation of this carburetter is illustrated in the diagram (fig. 48), and the detailed construction is shown in fig. 49. In principle this carburetter consists of a simple jet-in-tube carburetter (jet G in tube A), with the addition of a compensating jet H and a starting and slow-running jet *a*. The suction of the engine has no effect on the quantity of petrol entering by the compensating jet H, since the latter has its origin F at the bottom of a vertical passage, which has its free end open to the air at the point O. The flow through the



B. Cover of Slow-running Jet.
E. Main Air Supply.
G. Main Jet (Central).
H. Compensating Jet (Annular).
I, F. Passage to Compensating Jet.
L. Cover of Main Jet.
M. Cover of Compensating Jet.
O. Air Hole.

P. Throttle Valve.
S. Jet Orifices.
T. Float-chamber Cover.
V. Float Chamber.
X. Choke Tube.
a. Slow-running Jet.
b. Air Hole.
m, *n*. Petrol Level.

Fig. 49.—Zenith Carburetter.

compensating jet depends only on the size of the orifice I and the constant pressure in the float chamber V, and is, therefore, the same at all engine speeds. At high speeds the deficient supply through the jet H compensates for the excess through the ordinary jet G.

The starting and slow-running jet *a* is subject to suction through the passage U, which opens against the edge of the nearly closed throttle valve P.

Referring more particularly to the constructional view (fig. 49), we will describe first the means necessarily provided in all carburetters by which the petrol level is kept constant whatever the pressure or head of the petrol supplied. The petrol coming from the tank to the float chamber V is admitted or cut-off by a conical-ended needle valve, which passes through the hollow centre of the float, and is provided with a collar engaging levers pivoted to the cover T. When the petrol level *m*, *n* in the float chamber falls sufficiently, the float allows the levers to lift the needle valve and admit more petrol. As the level *m*, *n* rises, the float lifts the weighted ends of the levers, and thereby lowers the needle valve into the closing position. The float and levers should be adjusted so as to keep the petrol level very slightly below the outlet from the jets.

The two jets, main and compensating, are disposed concentrically one within the other, and both have their opening at S, the main jet being in the centre and the compensating jet around it. It will be seen that the annular space H is connected through F to the top of the gauged orifice I, thus allowing the petrol delivered by this orifice to be conducted to S. The main jet is, of course, fed direct from the float chamber.

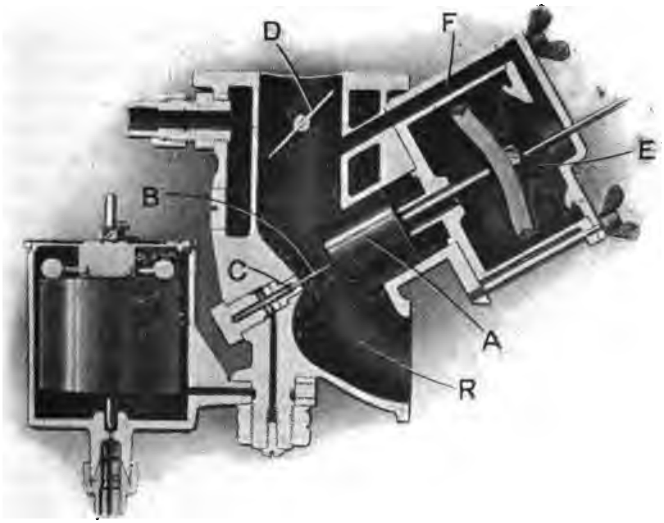
The orifices at S both open into the centre of the choke tube X, which regulates the velocity of the air necessary to ensure proper atomization of the petrol.

At very low engine speeds, such as obtain when the car is stationary and the engine is just "turning over" out of gear, the depression or suction on the jets at S is very weak, since the throttle P is nearly closed. This being so, practically no petrol can pass from the jets, so that the mixture for slow running would be too weak. At this period, however, the suction at the point U is very strong, and advantage is taken of this to provide a suitable mixture for very low speeds, by connecting the orifice U with the petrol in the well above the orifice I.

It will be seen from the preceding remarks that for easy starting and good slow running the throttle must only be opened very slightly to ensure a good suction at U. This suction is communicated by a channel drilled in the carburetter through the centre of B to the auxiliary jet *a*. The petrol then passes through these passages forming, with the air entering through O and *b*, a very rich mixture, which is emitted from U, whence it is carried to the cylinders by the air rushing past the edge of the throttle valve P.

S.U. Carburetter.—In this carburetter, shown in section in fig. 50, the size of the petrol jet, the size of the air passage, and the suction on the jet, are automatically varied by a movable piston or plunger A. The detailed construction will first be considered. The float and needle valve maintain the petrol level, as usual, very slightly below the jet C. A needle valve B fixed to and concentric with the piston A is formed with a tapered end, which passes into the jet C. As the piston and needle move in or out, the effective size of the jet is made smaller or larger, and the size of the choke tube R or choked portion of the air conduit is also varied in such a way as to give the correct mixture. The upper end of the piston-rod carries a mushroom disc, forming the movable end of a bellows chamber E, the interior of which is connected by a passage F to a point in the air conduit near the usual throttle valve.

The action of the carburetter is as follows:—When the engine is running dead slow and unloaded, the piston A moves downwards to within $\frac{1}{32}$ inch of the jet opening, and thus obstructs the air passage across the jet. This very small opening of the passage ensures that the air passing through it shall move with sufficient velocity to atomise the fuel then being delivered through the jet. As the throttle valve D is opened and the suction increases, the pressure in the jet chamber above the jet decreases, and the



A. Movable Piston.
B. Tapered Needle Valve.
C. Jet.
D. Throttle Valve.
E. Bellows Chamber.
F. Passage to Bellows Chamber.
R. Choke Tube.

Fig. 50.—S.U. Carburetter.

suction effect is transmitted to the interior of the bellows chamber E through the passage F.

This has the effect of lifting the lower face of the piston A away from the jet, so giving a larger air passage, and at the same time drawing the tapered needle B further up the jet opening C, and allowing a proportionally larger volume of fuel to be sprayed into the air current. When the throttle is closed, the converse action takes place; the suction of the engine decreases, the pressure in the bellows chamber E rises, and the piston moves downward. There is thus a continual automatic variation of the supply of air and petrol, according to the demands of the engine.

Engine Starters.—Petrol engines are, with very few exceptions, of such moderate dimensions that they can be turned by hand sufficiently quickly to start them. A handle having a ratchet connection with the crank shaft is generally provided for this purpose. Although power-starting apparatus is not essential, it is undoubtedly a great convenience on motor cars, and during the last few years a great deal of attention has been given by motor engineers to the question of power-driven engine turning gears for motor-car engines.

Compressed air has been used successfully in several instances. There are, broadly, two such methods, in each of which a small air compressor driven by the engine supplies air to a cylindrical receiver. In one method the compressed air drives a small motor having at least three cylinders, and this motor turns the engine through a reducing gear, a small toothed pinion on the shaft of the starting motor being put into gear when starting with a ring of teeth on the engine flywheel. In the other method compressed air is distributed directly to the engine cylinders by a valve, which supplies each cylinder during its working stroke. The valve is rotated at half engine speed. Neither of these methods has been widely used.

Electrical starting gear is now largely and increasingly used, particularly in America. It has the great advantage that the lighting of the car can be effected electrically from the same system, and in some cases the engine ignition also. In some electric car lighting and engine-starting systems a dynamo driven by the engine supplies current to accumulators, which deliver it, when required, to the lamps or to an electromotor adapted to drive the engine through a reducing gear. In other systems an electrical machine adapted to function either as a dynamo or as a motor delivers electric current to the accumulators or receives it therefrom when starting the engine. As these electrical systems merely turn the engine, and can be applied to or removed from it without affecting its normal working, any more detailed description is held to be beyond the scope of this book.

CHAPTER VII.

DIESEL ENGINES.

Principles.—Dr. R. Diesel introduced, about 1895, a very interesting oil engine, which has found considerable application on the Continent, and more recently in England, particularly since the Diesel patents expired.

In the Diesel engine the ordinary two- or four-stroke cycle is followed, but with this important difference that air only is compressed during the compression stroke, and the oil fuel is injected into the cylinder during the early part of the working stroke. The compression is much greater than is usual, and the air is, therefore, heated at the end of the compression stroke to such a high temperature that the fuel burns as it is sprayed into the cylinder. No other provision is needed or is used for ignition. This is an essential feature of the Diesel engine, by which it is distinguished from the hot-bulb or semi-Diesel engine to be described in Chap. VIII. The high compression tends to efficiency.

The air in the cylinder is compressed to about 450 to 500 lbs. per square inch, and the temperature accordingly raised to over 600° C. A small quantity of air is compressed independently to 650 or more lbs. per square inch, in order that it may be used to inject the oil, the excess of pressure necessary for injection being at least 200 lbs. per square inch. During the first part of the working stroke this auxiliary air violently forces in the oil and breaks it up finely so as to facilitate combustion. The oil ignites by contact with the highly compressed air in the cylinder, and the combustion continues during the injection period, which at full load covers about one-tenth of the working stroke. The combination of a very high compression temperature with the violent pulverization of the fuel by the high pressure air used to inject it ensures very certain and complete combustion.

The combustion is thus comparatively slow without the sudden rise of pressure or explosion experienced in the type of internal combustion engine in which a mixture of oil and gas or vaporized fuel is compressed. During the injection period the pressure remains nearly constant, and then falls in the usual way as the piston moves forward.

The temperature attained on the compression stroke is much in excess of the lowest temperature needed to start combustion. This margin facilitates the vaporization of even the heaviest fuel injected, and ensures its complete combustion. Practically any kind of oil, however crude, may be used with success, although some oils make the engine very dirty. The direct injection engine is the only one in which the very crude, viscous oils can be used. Such oils can only be very partially vaporized by heat. The forcible division into fine particles by the violent action of the highly compressed injection air is the only method (with the exception of the mechanical atomizer described in Chap. VIII.) by which the oil can be sufficiently mixed with air to burn.

It is in large installations, such, for instance, as in electric generating stations or in ships that the Diesel engine shows to the greatest advantage. The high pressures of air required in the Diesel engine and the necessity for the use of two or three-stage air compressors enable the ordinary oil engines, such as those of the hot-bulb type, to compete on equal or nearly equal terms where comparatively small powers are required.

The Diesel engine has a higher efficiency than any other heat engine. Tests have shown that the efficiency in some installations is as high as 41 per cent.—that is to say, the indicated horse-power may amount to 41 per cent. of the energy of the fuel used. This is distinctly higher than the highest efficiency obtainable in ordinary gas engines or other internal combustion engines having a lower compression, and is more than double the efficiency of a good steam engine plant.

High compression is only possible in engines in which pure air is compressed. Engines in which a mixture is compressed are liable to pre-ignition unless the highest compression pressure is kept so low that the temperature of the mixture does not reach the igniting point. Such engines may even then be liable to pre-ignition from incandescent pieces of carbon in the cylinder (in the case of a dirty engine), or from small projections, which, owing to bad design or some temporary cause, become overheated. The very high pressure occurring before the piston reaches the end of its stroke, in consequence of premature ignition, produces very severe stresses on the bearings and other moving parts, and may even reverse the engine or cause breakage.

Four-stroke Cycle.—The cycle of operations in a four-stroke vertical, single-acting Diesel engine is shown diagrammatically in fig. 51.

(1) *Suction Stroke.*—The inlet valve is open and pure air is drawn in.

(2) *Compression Stroke.*—All three valves are closed, and the pure air is compressed by the return movement of the piston into the small

compression space, and becomes thereby very highly heated.

(3) *Working Stroke.*—The fuel injection valve is opened, and the fuel is injected by means of compressed air; this fuel is then ignited by the hot air in the cylinder and combustion takes place, followed by expansion of the gas as the piston is forced forward.

(4) *Exhaust Stroke.*—The exhaust valve is opened, and the waste gases are exhausted into the atmosphere.

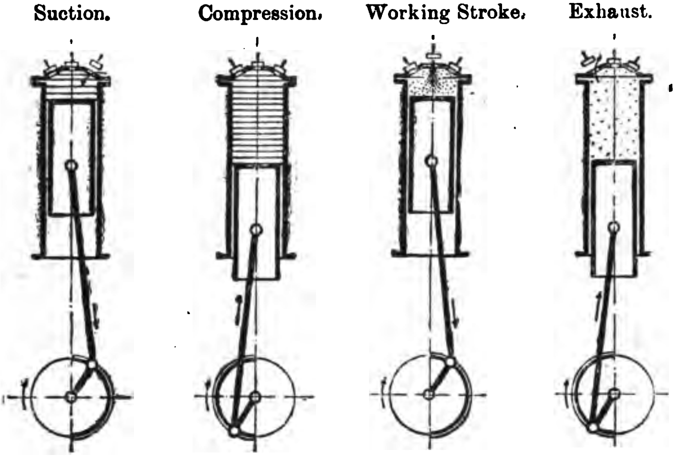

Suction. Compression. Working Stroke. Exhaust.

Fig. 51.—Four-stroke Diesel Cycle.

The indicator diagram for such an engine is shown in fig. 53. The pressures are given in atmospheres, the average value of which is 14·7 lbs. per square inch. The maximum pressure during the injection period is about 31 atmospheres, which equals 31 × 14·7 = 456 lbs. per square inch.

The parts of the diagram corresponding to the several strokes are indicated by the numerals 1 to 4.

Two-stroke Cycle.—The cycle of operations in a two-stroke cycle Diesel engine is shown diagrammatically in fig. 52. In this engine the burnt gases are exhausted through ports uncovered by the piston when at the lower end of its stroke. Pure air is forced in by a pump (not shown) through two valves in the cylinder head.

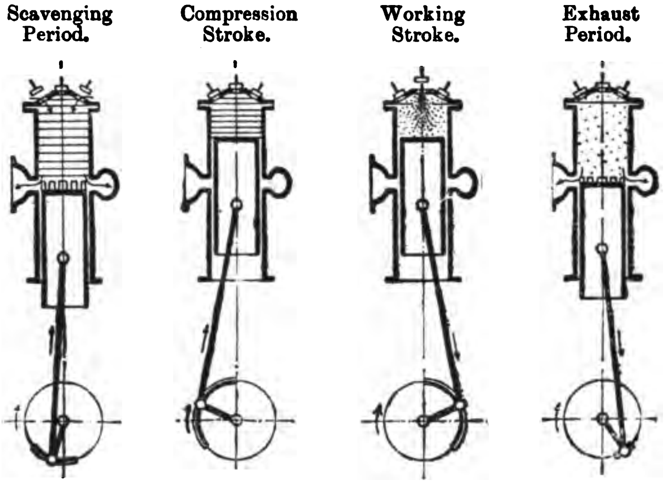


Fig. 52.—Two-stroke Diesel Cycle.

The series of operations is as follows:—

(1) *Scavenging period*, in which air admitted through the valves in the cylinder head forces out the residue of the exhaust gases and fills the cylinder with pure air in preparation for the

(2) *Compression stroke*, which is followed by the

(3) *Working stroke*, which comprises an injection period and an expansion period, followed by the

(4) *Exhaust Period.*—This commences with the

uncovering of the exhaust ports by the piston towards the end of the working stroke, and is followed by the scavenging period. The exhaust and scavenging periods overlap.

Fig. 53 shows the indicator diagram for this engine. The four principal periods are indicated by the numerals 1 to 4.

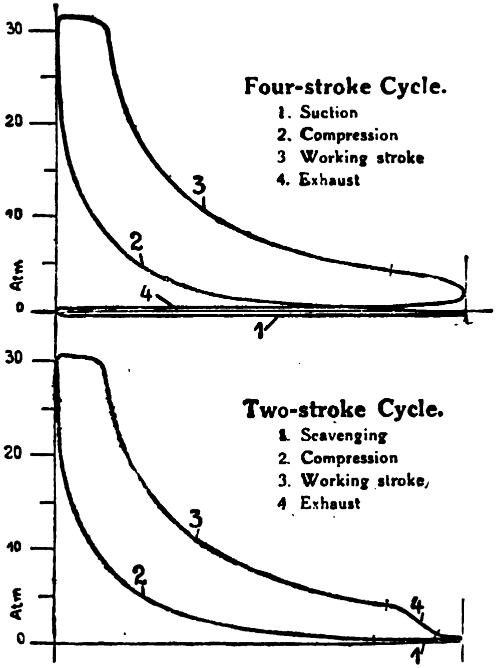
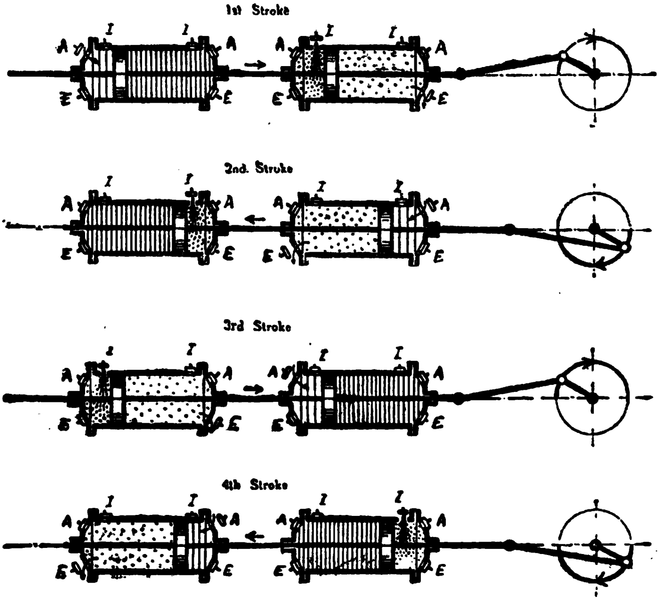


Fig. 53.—Diesel Indicator Diagrams.

The Diesel principle is peculiarly suitable for a two-stroke engine, since a sufficient quantity of pure scavenging air may be used to blow out all the exhaust products, while. owing to the compression of pure air only, there is no possibility of any unburnt fuel being blown into the exhaust and lost. Reference to the two-stroke cycle described in Chap. II. will enable these differences to be appreciated.

In the one case none of the new charge can be lost by passing out with the exhaust, since it is not injected into the cylinder until the end of the compression stroke, while in the other case a mixture of air and fuel is used both for scavenging and for filling the cylinder. In the latter case some mixture of the exhaust and the incoming charge is unavoidable, and, therefore, loss of unburnt fuel in the exhaust



A. Air Admission Valves. E. Exhaust Valves.
I. Fuel Injection Valves.

Fig. 54.—Four-stroke Double-acting Tandem Engine.

or retention of some of the exhaust products in the cylinder or both of these effects is bound to occur.

Four-stroke Double-acting Tandem Engine.—The cycle of operations on the M.A.N. large four-stroke tandem double-acting horizontal engines is shown diagrammatically in fig. 54. The general arrangement of these engines is similar to that of the large M.A.N. gas engines described in Chap. V. Each end of each cylinder follows the four-stroke cycle described above, and on each stroke of the engine one of the cylinders is performing its working stroke. There is thus a continuous turning effect except on the dead centres.

Fig. 54 should be studied in conjunction with the table of operations given on p. 79 in connection with the M.A.N. tandem double-acting gas engine.

Diagram of Engine and Appurtenances.—The essential elements in a four-stroke Diesel engine plant, including the engine and its various appurtenances, are shown diagrammatically in fig. 55, and are as follows :—

> A cylinder A is surrounded by a water-jacket to keep it cool. In the cylinder works a piston, which is connected by a rod to the crank shaft in the usual way.
>
> The head of the cylinder is provided with an air valve B, an exhaust valve C, and a fuel valve D, all these valves being generally closed by springs and opened when required by cams carried by a cam shaft driven at half engine speed. Only the operating gear for the fuel valve is shown in the drawing.
>
> A fuel pump E, driven by the cam shaft, is regulated by the governor G, so as to vary the quantity of oil delivered in accordance with requirements.

A two- or three-stage air compressor H supplies air at a very high pressure for injecting and pulverizing the fuel.

The plunger fuel pump E draws oil from the fuel tank through the pipe J and past the suction valve H into the pump cylinder. On the return stroke the plunger returns oil past the suction valve until it closes, and then forces the remainder of the oil up the delivery pipe K and through the non-return valve L in the cylinder head. The point at which the pump suction valve H closes is determined by the governor in such a way that just sufficient oil is retained in the

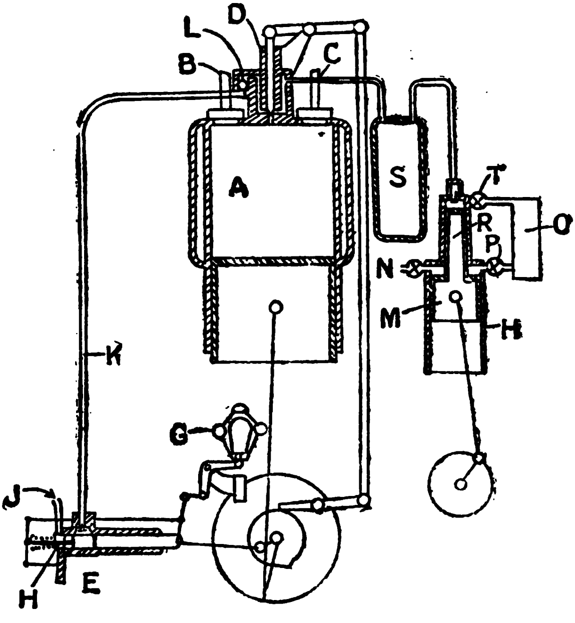


Fig. 55.

pump cylinder and sent up the delivery pipe to deal with the load then on the engine.

The two-stage air compressor is constructed and works as follows :—The plunger comprises two pistons of different diameter working in upper and lower cylinders. The lower and larger piston M, on its downward stroke, draws in air through the non-return valve N, and on its upper stroke compresses this air into the intermediate receiver O past the non-return valve P. The smaller piston R, on its downward stroke, draws air from the intermediate receiver O into the small cylinder past the non-return valve T. On the upward stroke, the small piston compresses this air into the final reservoir S at a pressure of at least 650 lbs. per square inch.

In a two-stroke Diesel engine, the only substantial differences are—(1) the cam shaft runs at the same speed as the crank shaft, and (2) a low-pressure blower or air compressor of large capacity is needed to supply the scavenging air for the engine cylinder.

Various Types.—Diesel engines are made of many different types, and of various sizes. The following may be mentioned particularly :—

(*a*) Horizontal four-stroke engines similar to the gas engines described in Chap. IV., and the Ruston-Proctor and Blackstone engines to be described in Chap. VIII.

(*b*) Small vertical four- or two-stroke engines developing from 8 horse-power, used for various purposes, such as small electric light installations, or as auxiliary motors for yachts or fishing boats.

(*c*) Vertical engines with one, two, three, four, six, or eight cylinders working on the two- or four-stroke cycle, for use in electric light stations, general power purposes, ships, and submarines.

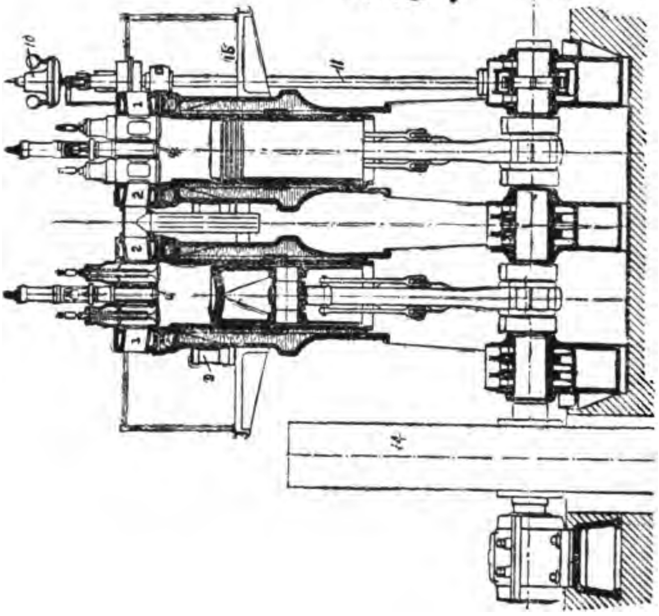


Fig. 56.

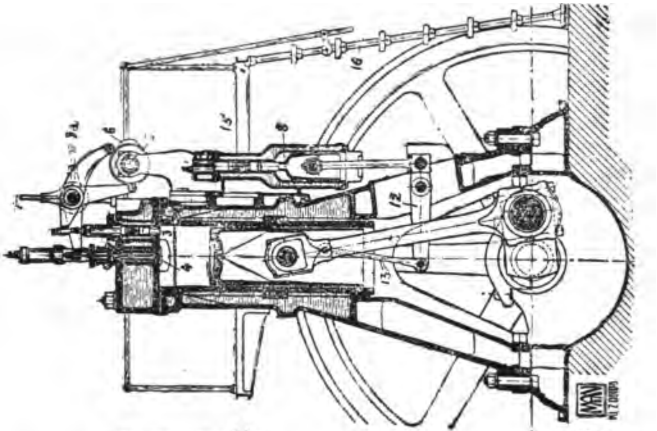


Fig. 57.

M.A.N. Vertical Four-stroke Engine.

Such engines may develop up to 250 or even more brake horse-power per cylinder.

(*d*) Large horizontal stationary two-stroke engines, with two pistons in one cylinder, similar to the Oechelhauser engines described in Chap. V.

(*e*) Large tandem horizontal double-acting two- or four-stroke engines.

The various parts of Diesel engines are generally similar to the corresponding parts of a steam or a gas engine, and are somewhat similarly designed. The differences are chiefly those of dimensions due to the far greater pressures that have to be dealt with. In the high-pressure cylinder of a steam engine the greatest steam pressure that has to be withstood rarely exceeds 200 lbs. per square inch, whereas in a Diesel engine working pressures of at least 500 lbs. per square inch have to be considered.

Figs. 56 and 57.

1. Exhaust Passage.
2. Inlet Passage.
3. Starting Valve.
4. Fuel Injection Valve.
5. Cam Shaft.
6. Cams.
7. Starting Lever in working position.

7*a*. Starting Lever in starting position.

8. Two-stage Air Compressor.
9. Fuel Pump.
10. Centrifugal Governor.
11. Governor Shaft.

12, 13. Levers operating Air Compressor.

14. Flywheel.
15. Platform.
16. Ladder to Platform.

M. A. N. Vertical Four-stroke Engine.—Figs. 56 and 57 show two sectional views of a two-cylinder vertical stationary engine of about 80 horse-power per cylinder. The two cranks are arranged side by side, so that both pistons move up and down together.

The cylinders fire alternately, so that each down stroke is a working stroke. The crank shaft is mounted in four bearings, one bearing being outside the flywheel 14. Exceptionally long trunk pistons are connected directly to the small ends of the connecting-rods. The cylinder liners are fitted into outer shells, which are cast in one with the supporting columns, and are bolted to the bedplate, the space between the liners and outer shells forming a water-cooling jacket. The bottom of the bedplate forms an oil catcher. The cylinder heads each consist of a massive water-cooled casting having exhaust and inlet passages 1, 2 with their exhaust and inlet valves, a centrally placed fuel injection valve 4, and a starting valve 3. Each valve is contained in a separate detachable cage in the cylinder head, the inlet, exhaust, and starting valves being of the ordinary lift type opened by cams and closed by springs. The valves are all operated by cams 6 on a half-speed cam shaft 5 acting through rocking levers. The starting valve is put into operation when starting the engine by adjusting the bearing of its rocking lever so as to move it closer to the cam shaft. With this object, the rocking lever oscillates on an eccentric pivot, which can be turned by a hand lever from the starting position 7*a* to the working position 7, or *vice versâ*. When in the starting position 7*a* the starting valve is opened and closed at the proper times, so as to admit high pressure air to turn the engine until it fires in the usual way. The double piston of the two-stage water-cooled air compressor 8 is connected to one end of a rocking lever 12, the other end of which is connected by a link 13 to a point near the small end of one of the connecting-rods. The quantity of oil delivered by the fuel pump is regulated by a centrifugal governor 10 mounted at the upper end of a vertical shaft 11 gearing with the crank shaft. A railed platform 15 runs right round the upper part of the cylinders, and is approached by a ladder 16.

Cylinder of Motor Ship "Fionia."—The Diesel engines described hitherto have all been furnished with trunk pistons—that is to say, pistons which form also the crosshead or guide for the small end of the connecting-rod. Such engines have the great advantages of shortness and simplicity, but when large cylinder diameters are in question, several considerations necessitate the use of an outside crosshead connected by a piston-rod to a short piston. These considerations are, broadly, (1) the greater difficulty of cooling arge pistons and the consequent bad working condition for the gudgeon-pin bearings, and (2) the greater wear of large cylinders and the expense of fitting new cylinder liners as the result of wear. In regard to (1), large pistons generally have to be oil or water-cooled, so that no room is left for the connecting-rod end, which is also very large. In regard to (2), the fact that the connecting-rod is oblique or inclined to the centre line of the engine during the greater part of the working stroke means that the small end exerts a considerable side thrust on the cylinder wall through the intermediary of the trunk piston. The intensity of this thrust on the cylinder wall becomes greater the larger the cylinder, for the reason that whereas the bearing surface of the cylinder wall is always proportional to the diameter, the power developed increases as the square of the diameter. Moreover, the replacement of a cylinder liner becomes relatively more expensive the larger the engine, until a stage is reached when it pays to substitute the outside crosshead and guides, piston-rod and short piston, for the simple trunk piston. The piston is thus relieved of any side thrust, and the tendency of the cylinder to wear on one side and become oval instead of circular

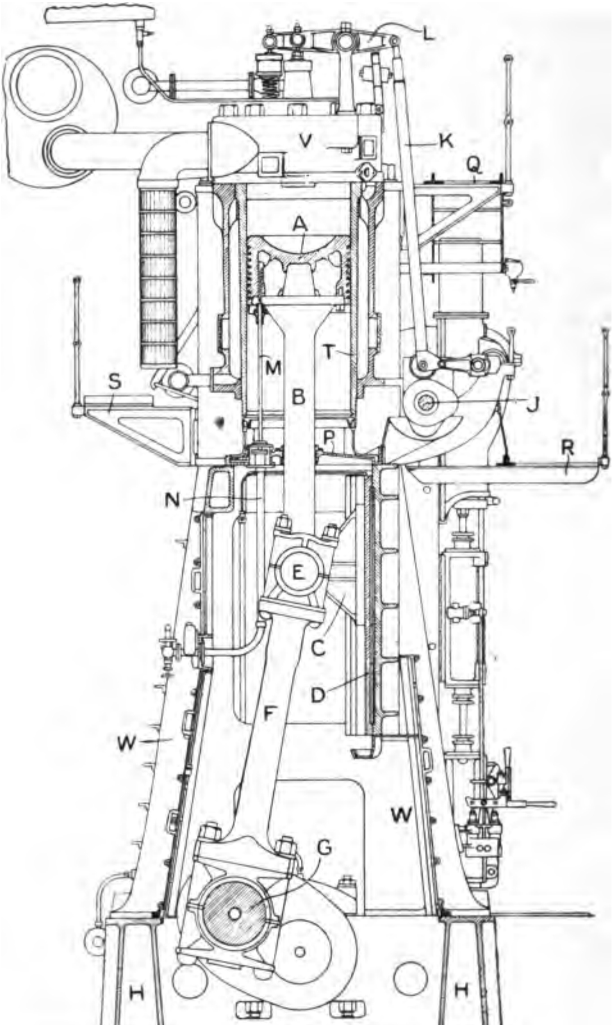


Fig. 58.—Cylinder of Motor Ship "Fionia."

is removed, all side thrust being taken by the crosshead and its guide.

A sectional view of one cylinder of such an engine working on the four-stroke cycle is shown in fig. 58. The cylinder diameter is 29 inches and the piston stroke 43 inches, while the brake horse-power per cylinder is about 260. A comparatively short piston A is connected by a piston-rod B to the crosshead C, which slides up and down on a vertical guide D carried by one of the main frame members W, the cylinders being bolted to the upper ends of the frames.

Carried by the crosshead C is a pin E, on which bears the forked upper end of the connecting-rod F, the lower end being connected to the crank pin G. The frame members W are secured to a bedplate H, which carries the main crank shaft bearing. The cylinder shown is one of a group of three.

Fig. 58.

A. Piston.
B. Piston-rod.
C. Crosshead.
D. Crosshead Guide.
E. Crosshead Pin.
F. Connecting-rod.
G. Crank Pin.
H. Bedplate.
J. Cam Shaft.
K. Valve operating Links.
L. Valve Rocking-Levers.
M, N. Piston Water-cooling Pipes.
P. Tray for Leak Water.
O, R, S. Platforms.
T. Cylinder Liner.
V. Cylinder Head.
W. Main Frames.

The various valves in the cylinder head V are operated from the half-speed cam shaft J through links K and rocking levers L.

The piston A of this engine is water-cooled, the water being supplied to and removed from the piston by a pipe M, which moves up and down with the piston and telescopes in a fixed pipe N. Leakage is prevented as far as possible by a gland and stuffing-box, but no effort is made to prevent it entirely, as that would entail wear and loss of energy. The leak water is caught by a tray P, and is led to the same funnel as the outflowing water from the piston.

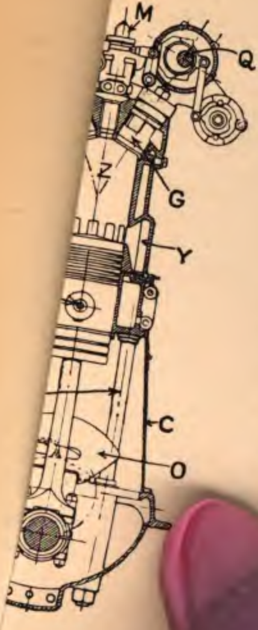
The overall height of the engine is about 26 feet, and several platforms are necessary in order that the parts may be accessible. Two platforms Q, R, giving access to the valve gearing, are shown at different levels on one side, and a single platform S is shown on the other side.

Sulzer Two-stroke Reversible Marine Engine.—The two-stroke cycle has been adopted for Diesel engines nearly as extensively as the four-stroke cycle. Although the very high pressure and the frequency of the working strokes render the design of such engines a difficult problem, these difficulties have been overcome by various makers. Messrs. Sulzer Bros.. whose works are in Switzerland, have constructed many two-stroke engines. Figs. 59, 60, and 61 show a four-cylinder engine manufactured by them for marine purposes. Fig. 59 shows a sectional elevation through the four cylinders Z, the scavenging air pump S, and the high-pressure two-stage air compressor E. Fig. 60 shows a sectional elevation transversely through one of the power cylinders, and fig. 61 shows a plan of the whole engine.

The crank shaft is carried in six main bearings, and a thrust bearing is provided at the flywheel end, to take the end thrust of the propeller shaft. The four main cranks are spaced at intervals of 90° to one another, the two end cranks 1, 2 being opposite and the two inner cranks 3, 4 also opposite each other but at 90° to the first pair.

Since there is one explosion on each down stroke of each cylinder, it follows that the turning impulses on the crank shaft occur at intervals of 90° of crank-shaft movement. The cylinders fire in the order

[*To face p.* 132.



g. 60.

A. Cylinder supporting Pillars.
B. Fuel Pump.
C. Cover-plates.
D. Base-plate.
E. High-pressure Air Pump.
F. Oil Pump.
G. Scavenging Valves.
H. Starting Hand-wheel.
J. Starting Valves.
K. Pistons.
L. Vertical Shaft driving
M. Fuel Injection Valves
Oilways in Crank Sha
Crank Balance Weight
dgeon Pins.
Shafts.
el.
g Pump.
Main Bearings.
nnecting-rods.
servoirs.
X.
Y.
Z. P
1, 2, 3, 4.

1, 3, 2, 4. In cylinders having a larger number of cylinders, the firing impulses occur at correspondingly shorter intervals.

The cylinders Z are water-jacketed, and are attached direct by steel pillars A to the main crank-shaft bearings in the base plate D. The lower end of each cylinder is provided with an exhaust belt Y, which opens into the exhaust pipe X, the exhaust ports being uncovered by the pistons. Trunk pistons K are shown in the drawings, but short pistons with separate crossheads are provided for the larger engines. Either type of piston may be water-cooled. The cranks and connecting-rods are completely enclosed by side and end cover plates C.

The fuel injection valves M (placed centrally in the cylinders), the starting valves J, and the scavenging air valves G are arranged in the cylinder head, there being two scavenging valves to each cylinder. All the valves are closed by springs and opened by direct-acting cams and rollers. Two cam shafts Q are arranged above the cylinders, and are driven at crank-shaft speed by a vertical shaft L and toothed gearing. Reversal of the engine is effected by shifting the cams on the cam shaft. The admission of liquid fuel is adjusted to suit the load on the engine by regulating the delivery of the fuel pump B, which has four plungers, one for each cylinder.

The main bearings, all the crank-pin bearings, and the upper ends of the connecting-rods are lubricated by a forced system, the oil being drawn from the base chamber by a cog-wheel or piston pump F, passed through an oil filter and cooler, and delivered under pressure to the bearings. Oil pipes T convey the oil to the main bearings; oil-ways N drilled in the crank shaft communicate with the crank pins, and oil-ways and pipes V on the connecting-rods carry oil to the gudgeon pins P.

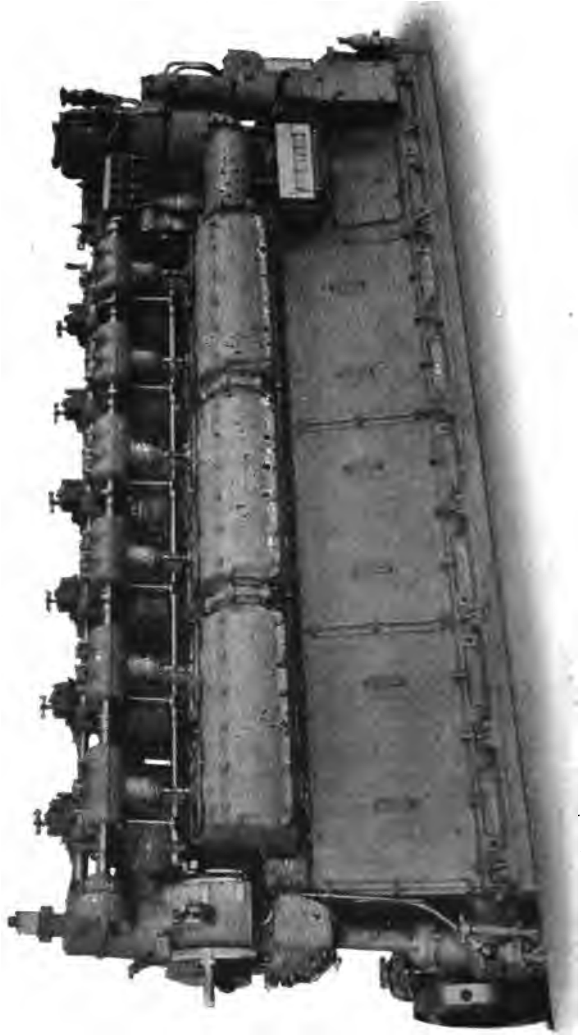


Fig. 62 —Sulzer Six-cylinder Two-stroke Engine.

Starting is effected by compressed air drawn from a reservoir and admitted to the cylinder by the cam-actuated starting valves J. Rotation of the hand wheel H first admits the starting air, while further movement of the hand wheel shuts off the air and brings the fuel valves into operation.

The double-acting scavenging pump S of large capacity is driven by a separate crank on the main crank shaft, and delivers air at a comparatively low pressure into the reservoir W, arranged alongside the working cylinders Z. The scavenging valves G control the supply of air from the reservoir W to the cylinders. The two-stage high-pressure air pump E is also driven direct from the main crank shaft, and stores air in a reservoir, from which it is drawn for fuel injection.

In some engines the scavenging air is admitted at the lower end of the cylinder, the scavenging valves being arranged near the exhaust ports, where they are better protected from the high-combustion temperatures.

These engines are also made with six cylinders working on the same crank shaft. Fig. 62 shows an external view of such an engine intended for use on a submarine. The construction of the cylinders, valves, and other working details, and the general structure, is similar in both the four- and the six-cylinder engines, but the arrangement of various parts, such as the air reservoirs, exhaust pipes, and compressors is varied in any particular installation to suit the limited space available.

General Arrangement of Marine Engine Plant.—Fig. 63 shows an elevation, a transverse section, and a plan of the engine room of a ship in which a four-cylinder Sulzer engine is installed. In this instance there is only one screw propeller, and plenty of space

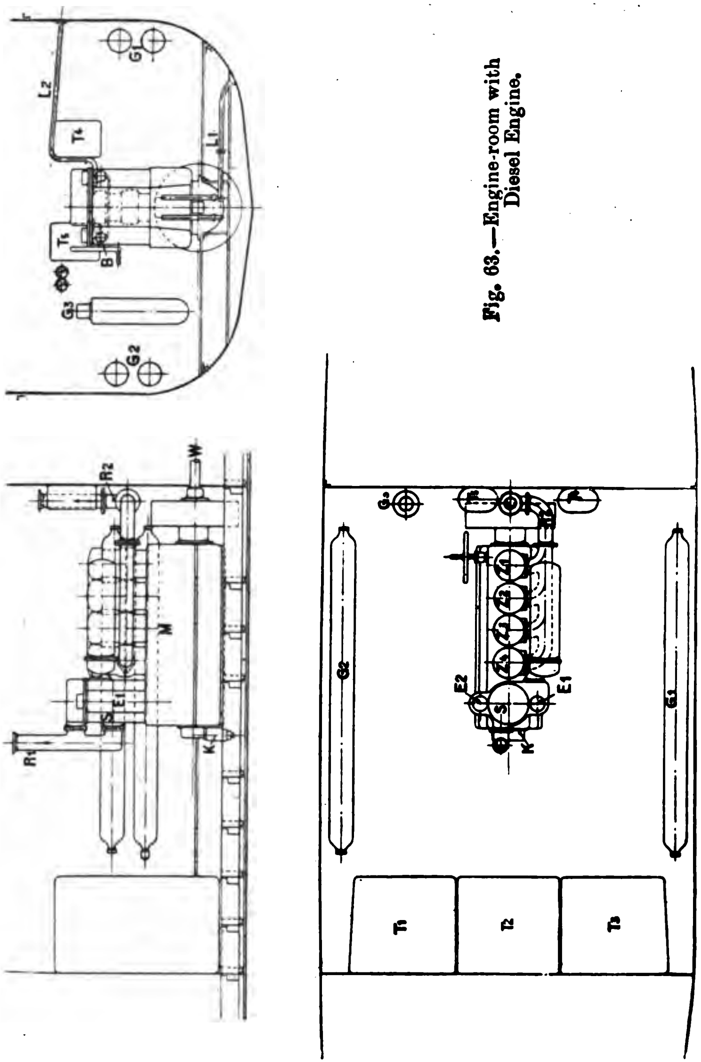


Fig. 63.—Engine-room with Diesel Engine.

is available. The following references will enable the disposition of the parts to be readily followed :—

M. Engine coupled direct with the Propeller Shaft W.
Z_1, Z_2, Z_3, and Z_4. Working Cylinders.
S. Scavenging Pump.
R_1. Air Intake for Scavenging Pump.
R_2. Exhaust Pipe with Silencer.
G_1. Starting Air Vessel.
G_2. Spare Air Vessels.
E_1 and E_2. Compressors for Injection Air.
G_3. Injection Air Vessel.
T_1, T_2, and T_3. Fuel Reservoirs.
T_4 and T_5. Fuel Vessels.
B. Fuel Pump.
K. Cooling Water Pump.
L_1. Cooling Water Pump Suction.
L_2. Cooling Water Pump Discharge.

Valve Timing for Two-stroke Engine.—The diagram, fig. 64, shows the valve timing of a vertical Diesel engine when rotating in the direction indicated by the arrow A. The various positions of the crank are

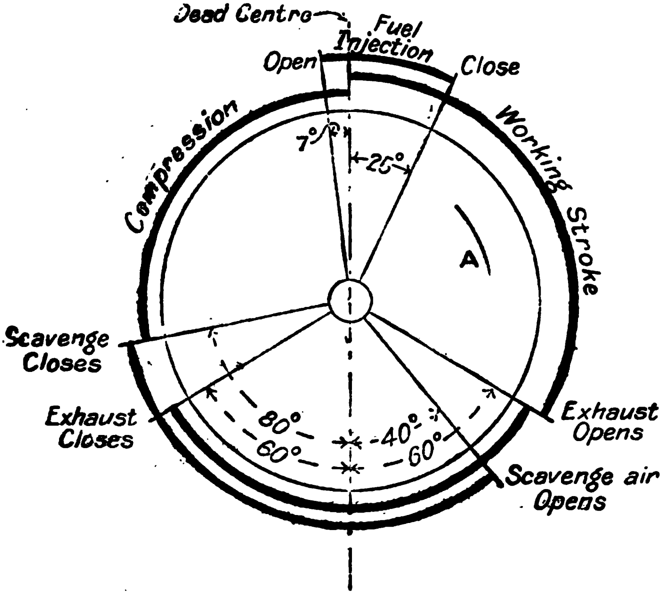


Fig. 64.—Valve Timing for Two-stroke Engine.

shown at the instant when the different events of the cycle occur. The exhaust opens before the scavenging air is admitted and closes earlier. Although the exhaust and scavenging periods occupy so much of the crank movement, the corresponding movement of the piston is comparatively small, since it is then at the lower end of its stroke and moving slowly. Similarly, the movement of the piston during the fuel injection period is quite small.

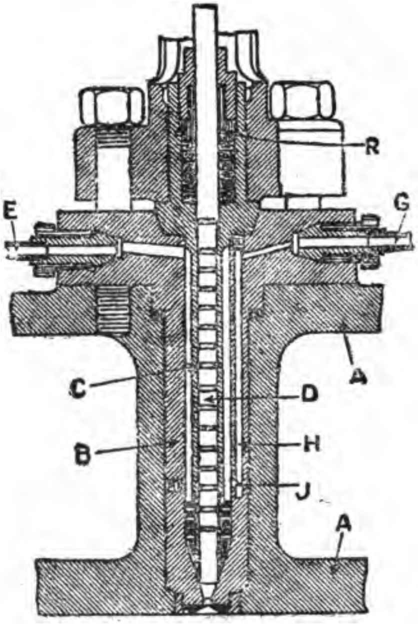


Fig. 65.—Fuel Injection Valve.

Fuel Injection Valve.—One of the most important parts of a Diesel engine is the fuel injection valve. If the highest possible thermal efficiency is to be attained, it is necessary that the liquid fuel should be injected into the cylinder in the form of a very fine spray, so that the combustion may be very rapid. In order to effect this very fine subdivision of the fuel, and at the same time force it into the cylinder against the high compression pressure, a device called a pulverizer is used, in conjunction with air compressed to a pressure of from 200 to 300 lbs. per square inch above the compression pressure.

Fig. 65 shows the form of injection valve and pulverizer adopted by the majority of makers for all kinds of fuel except the very heaviest crude oils, and fig. 66 shows an enlarged sectional view of the pulverizer. The valve body, the valve, and the associated parts can be removed as a whole from the opening in the cylinder head A, in which they fit. The annular space between the valve body B and the central stem or guide C for the central needle valve D is in direct communication with the injection air tank by means of the pipe E. The oil is led from the fuel pump through the pipe G and passage H to the lower part of the above-mentioned annular space. The oil supply pipe G and passage H are always full of oil, and each stroke of the pump forces a quantity of oil, the quantity being determined by the governor, through the hole J, which connects the oil passage H and the annular space. With the object of preventing leakage, a number of grooves are turned in the stem of

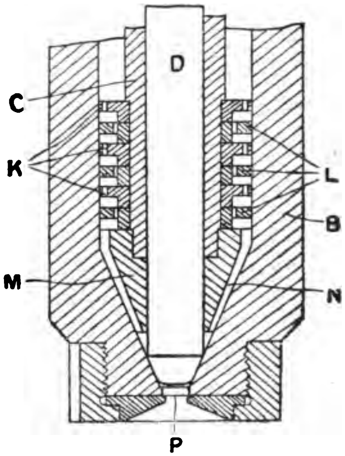


Fig. 66.—Injection Valve Pulverizer.

the needle valve, and it also passes through a special stuffing-box R.

The pulverizer consists of several annular obstruction plates having holes or slots so arranged that the orifices in one are opposite the metal of the next. In the construction shown in detail in fig. 66, six plates are arranged in the annular space, each plate being formed with a boss, so that the perforated parts of the different plates are spaced away from one another. Three of these plates K have a large number of small holes drilled round their peripheries, while the other three L, which are arranged alternately with the first three, have a number of similar holes drilled close to the bosses. The injection air and fuel necessarily take an indirect course through the series of holes, and the fuel is divided into very fine drops, and not merely into fine streams.

Below the obstruction plates is a conical member M, which fits into a conical part of the shell B, and is provided with a large number of grooves N for the passage of the oil and injection air. The conical end of the needle valve closes a small orifice P placed about level with the cylinder end.

A strong spring tends to keep the valve closed, and a cam on the cam shaft operates through link-work to hold it open during the injection period. When the valve is lifted, the oil in the annular space, together with some injection air, is forced through the obstruction plates and through the grooves in the conical member, and spreads out into the cylinder after passing through the final orifice P.

The lift of a needle valve varies from $\frac{1}{50}$ to about $\frac{1}{10}$ inch.

CHAPTER VIII.

OIL ENGINES.

Introduction.—This chapter is intended to deal with engines using (1) kerosine or paraffin, (2) crude or unrefined oils, or (3) residual oils—that is, oils from which the more volatile constituents have been removed. Fuel oils of this character, particularly those mentioned under (2) and (3), require a considerable amount of heat to vaporize or gasify them sufficiently to enable them to mix with air and form an explosive mixture.

Oil engines for use with kerosine or paraffin have been made for many years; the fuel in such engines is generally vaporized by heat and mixed with air, the mixture being drawn into the cylinder on the suction stroke and then compressed; or air alone is compressed on the compression stroke and then mixed with the vapour. The ignition is effected by the heat of the walls of an unjacketed chamber or by some refractory material kept hot by the successive explosions. Engines of this type work on the four-stroke cycle.

Although these engines have been very widely used, they have always been open to the objections that the compression must be kept low to avoid pre-ignition, and that more or less refined oil is always required for working, while in many countries crude oil could be obtained very much more cheaply than any other fuel. There is still a large home market for engines using kerosine (particularly for small powers), but for export purposes and for the medium and larger powers, there is a large and increasing demand for engines capable of using crude or residual oil.

Manufacturers were not able to supply this demand properly until they adopted the modern hot-bulb engine, in which the oil is injected by a force pump, or by compressed air into a bulb or unjacketed chamber kept hot by the heat resulting from the previous explosion and from the compression. The temperature of the bulb is sufficient to vaporize and ignite the fuel, which is injected at the end of the compression stroke, pure air only being compressed.

Some engines of this class resemble Diesel engines very closely, and the explanations of the four- and two-stroke Diesel cycles given in Chap. VII. apply to all those engines now under consideration in which pure air is compressed.

This chapter will deal with engines of both of the above-mentioned types, viz. :—

(1) Low compression engines in which a mixture of air and paraffin vapour is compressed.

(2) High compression engines in which pure air is compressed and the fuel is injected at about the end of the compression stroke.

Petrol or benzine engines using light or easily vaporized fuel are not included, but are dealt with in Chap. VI. Diesel engines are also excepted, being discussed in Chap. VII. This chapter does, however, deal with the so-called semi-Diesel engines, which are generally simply hot-bulb engines working with a higher compression than is usual in the paraffin engine. The term "semi-Diesel" is applied somewhat loosely, and engines described by one maker as "semi-Diesel" may differ very little from engines described by another maker as crude-oil engines, or merely oil engines.

Oil-injection engines work on both the two- and four-stroke cycles, and there is considerable difference of opinion as to which is the better. Broadly speaking, the superiority of either kind may be said to depend upon the service required. The two-stroke engine gives more power for the same weight of engine, but is not quite so economical as regards fuel consumption. There is also greater difficulty in keeping the pistons and cylinders cool, in consequence of the greater number of working strokes. The valve gearing of the two-cycle engine is much simpler; in fact, there are often no valves other than the fuel-injection valve. As is usual in a new and rapidly developing industry, there are many and various designs of crude-oil engines, and it will probably be some years before experiment and experience result in some degree of uniformity.

Ruston-Proctor Four-stroke Petroleum Engine.—These engines are of the kind in which a mixture of air and vapour is compressed on the compression stroke, and are intended for use with paraffin. They are made in various sizes, developing from 3 to 55 maximum H.P. The continuous working load for periods exceeding two consecutive hours should be about 10 per cent. less than the maximum load.

It will be seen from the section shown in fig. 67 that these engines are in their general characteristics somewhat similar to the horizontal gas engines described in Chap. IV.

The cylinder and the combustion chamber E, into which the valves open, are water-jacketed; the cam shaft (not shown) is placed alongside the engine, and is worked from the crank shaft by skew gearing. The clearance space is very large, and the pressure at the end of the compression stroke is, in consequence, low, being only about 50 lbs. per square inch. Exhaust takes place as usual through the lower valve, while the upper valve admits pure air, the valve operating gear not being shown. The pure air supply is drawn past a throttle valve H, which may be set by hand.

A. Vaporizer.
B. Igniter.
C. Flywheel.
D. Fuel Pump.
E. Combustion Chamber.
F. Ignition Valve
G. Main Air Valve.
H. Air Throttle Valve.
J. Fuel Pipe to Vaporizer.
K. Cooling Water Outflow.
L. Lubricator for Piston and Gudgeon Pin

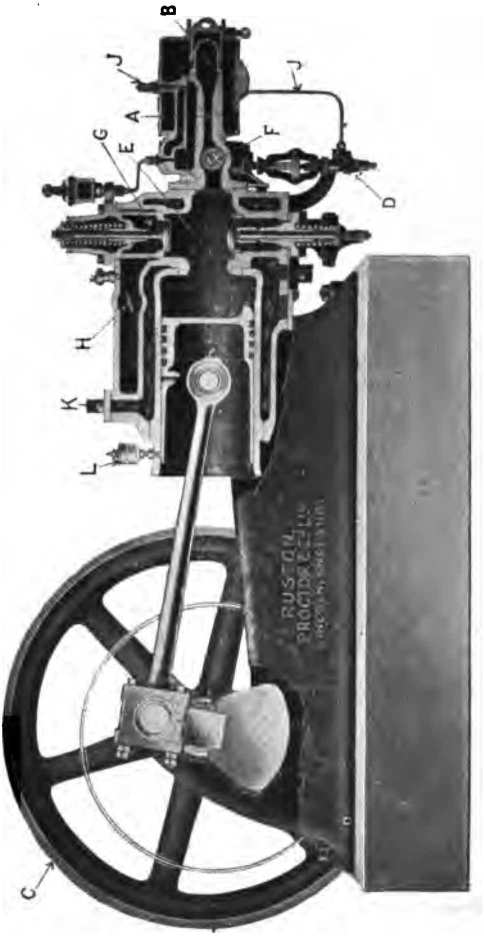


Fig. 67.—Ruston-Proctor Four-stroke Petroleum Engine.

A rotary valve F, also operated from the cam shaft, connects the cylinder, when required, with the vaporizer A and the igniter B, which remain at a sufficiently high temperature to effect the vaporization and ignition of the fuel, by reason of the fact that they are not water-jacketed. A small oil pump D feeds the oil from a tank to the vaporizer A by means of the pipe J.

Starting.—The vaporizer A and the igniter B are first heated by a lamp to enable the first few revolutions to be made, after which the lamp can be removed, the vaporizer and igniter being kept hot by the heat of combustion. When the vaporizer has been heated sufficiently by the lamp, the engine is started by giving a few turns to the flywheel, the device for relieving the compression being then in operation.

The ordinary cycle of operations is as follows :—

Suction Stroke.—During the suction stroke the vaporized oil is drawn into the cylinder through the then open vapour valve F, and is mixed with air, which is simultaneously drawn in through the main air valve G.

Compression Stroke.—The valve F is closed during the compression stroke, so that the explosive mixture is compressed into the clearance volume at the end of the cylinder.

Working Stroke.—When the compression stroke has been completed, the valve F is opened and the explosive mixture is ignited, in consequence of the high temperature of the vaporizer and igniter. It should be noted that the vaporizer and igniter are not water-jacketed, so that internally they remain approximately at the temperature of the explosion, whereas the walls of the cylinder are kept by the cooling water at a very much lower temperature.

Exhaust Stroke.—The products of combustion are expelled in the usual way through the exhaust valve.

When it is necessary to run at exceptionally light

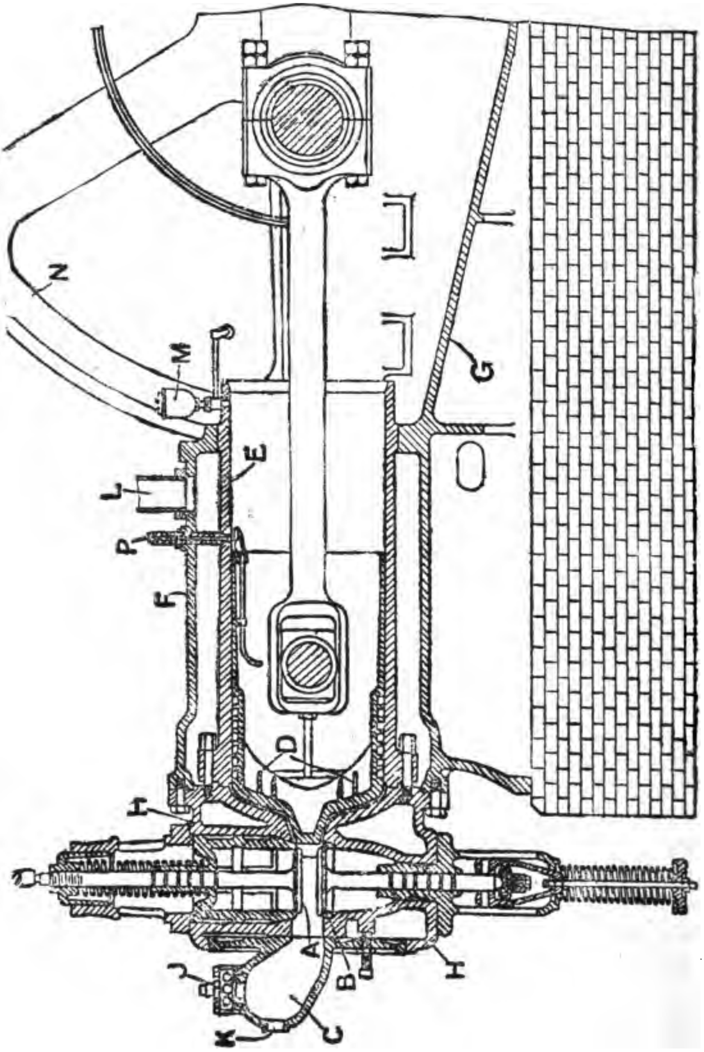


Fig. 68.—Ruston-Proctor Crude Oil Engine.

loads, the heat of explosion may not be sufficient to keep the vaporizer hot enough to ignite the mixture. In such a case, it may be occasionally reheated, or a small lamp may be left burning continuously.

Ruston-Proctor Crude Oil Engines.—Vaporizers or devices as described above for vaporizing oil before it is ignited can only be used with continued success on engines burning paraffin. The result of attempting to use a vaporizer with crude or residual oils is merely to distil or vaporize the lighter or more volatile constituents for use, leaving behind a carbon deposit which necessitates frequent stopping and cleaning of the engine. This objection is largely overcome in (1) engines of the Diesel type described in Chap. VII., and (2) hot-bulb engines to be described in the present chapter, by injecting the fuel directly into the cylinder at the end of the compression stroke and compressing only pure air. This results in rapid combustion of both the light and heavy constituents of the oil, and avoids heavy carbon deposits in the combustion chamber and on the valves.

Fig. 68.

A. Air Admission Valve.
B. Exhaust Valve.
C. Hot Bulb.
D. Piston-cooling Ribs.
E. Cylinder Liner.
F. Outer Shell.
G. Base Plate.
H. Combustion Head.
J. Fuel-injection Valve.
K. Water-snifting Valve.
L. Cooling-water Outflow.
M. Lubricator for Piston Pin.
N. Flywheel.
P. Lubrication Passage for Piston.

Ruston, Proctor & Co. manufacture an engine of the hot-bulb type, working with a much higher compression than the engine described above, and specially adapted to burn any kind of crude or residual oil. The pressure at the end of the compression stroke is about 300 lbs. per square inch, as compared with 50 lbs. per square inch in the other engine. Fig. 68 shows a longitudinal section. The upper valve A admits pure air, and the lower valve B serves for exhaust as before, but the two are closer together, so as to assist in reducing the clearance volume and so obtain the higher compression. With the same object, the piston is shaped so as to approach closely to the end of the cylinder. The fuel oil is injected at the end of the compression stroke into a hot bulb C *not water-jacketed*, the bulb forming part of the clearance volume.

The piston is very long, and cooling ribs D are cast on the inside. The cylinder liner E is placed within an outer casing F formed in one with the base plate G, the space between the two serving as a water-jacket. At its outer end the cylinder liner is supported directly by the outer casing and at its inner end by the combustion head H, which is bolted to the outer end of the casing and is cast with water-cooling spaces. To the outer end of the combustion head is bolted the flange of the hot bulb C. The fuel injection valve J is bolted to the top of the bulb. To prevent the hot bulb from becoming too hot, a water-snifting valve is arranged horizontally in the end K of the bulb. During the suction stroke this valve admits a small quantity of water, which takes up some of the heat from the walls of the bulb and is converted into steam. A cock is fitted to regulate the water feed to the snifting valve, so that it keeps the bulb externally at a black heat, considerably below red heat.

The ignition of the charge is effected by the rise of temperature due to the compression, together with the heat of the combustion chamber or hot bulb.

In hot-bulb engines working with a high compression pressure, as in the engine now under consideration, the injection of the fuel into the hot bulb presents some difficulty. Some engines—*e.g.*, the Blackstone engine, to be described later—use compressed air, but most—*e.g.*, the Ruston—employ a mechanical injector or atomizer.

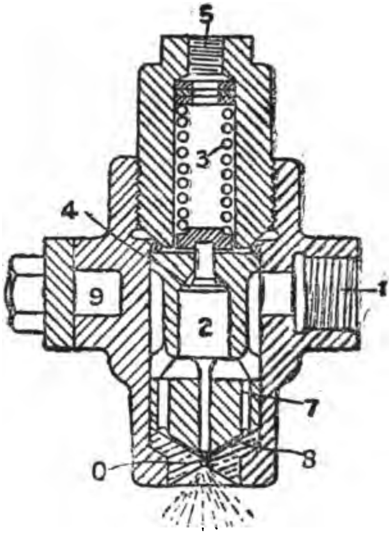


Fig. 69.—Ruston-Proctor Mechanical Fuel Atomizer.

A sectional view of the Ruston mechanical atomizer, as arranged on top of the hot bulb, is shown in fig. 69. At or about the end of the compression stroke a small quantity of fuel is forced to the atomizer, through a pipe connected to the opening 1. A duplex valve 2, loaded by a powerful spring 3, is lifted by the pressure of oil, at each stroke of the oil fuel-pump. The valve has two seats of different diameter; the smaller seat closes the opening to the combustion chamber, while the larger seat 4, when the valve is in its raised position, closes a leak pipe 5 connected to the suction side of the oil pump. The pressure of the oil acting on the lower end of the large part of the valve lifts it and forces it up to its larger seat 4. When the valve lifts, the oil is forced through passages 7 and spiral channels 8, converging to a central outlet O, so that it emerges on the other side of the nozzle in a cone-shaped cloud of oil particles. The movement of the valve between the limits set by its larger and smaller seats is about $\frac{1}{40}$ inch. Some of the ordinary cooling water is circulated through a passage 9, partly surrounding the valve body.

A somewhat diagrammatic sectional view of the fuel oil pump and governing gear is shown in fig. 70. A special cam (not shown) on the end of the ordinary cam shaft operates the plunger B on the pumping stroke, by means of a rocking lever, the return being effected by a spring. The cam is designed to give a very rapid delivery stroke, and this, together with the special construction of the atomizer, reduces the oil to a very fine spray. The fuel is drawn from the oil tank through the suction pipe A, and is delivered through the pipe H. A full charge of oil is pumped past the delivery valve C on each stroke, but not all of this reaches the engine cylinder; some is returned to the fuel tank through an overflow valve D, the amount so returned being regulated directly by the centrifugal governor E.

The governor varies the charge of oil delivered to the atomizer, according to the load on the engine. A rod F from the governor acts on a lever G, so as to rotate a spindle carrying a cam H. This cam, by means of a lever J, adjusts the amount of the opening of the overflow valve D, which returns a quantity of oil not required to the oil tank through an overflow pipe K, thus causing a corresponding reduction in the quantity delivered to the atomizer through the pipe H. The governor thus controls the lift of the overflow valve, and so regulates the speed of the engine within quite narrow limits. The fulcrum of the lever J may be adjusted by the screw L.

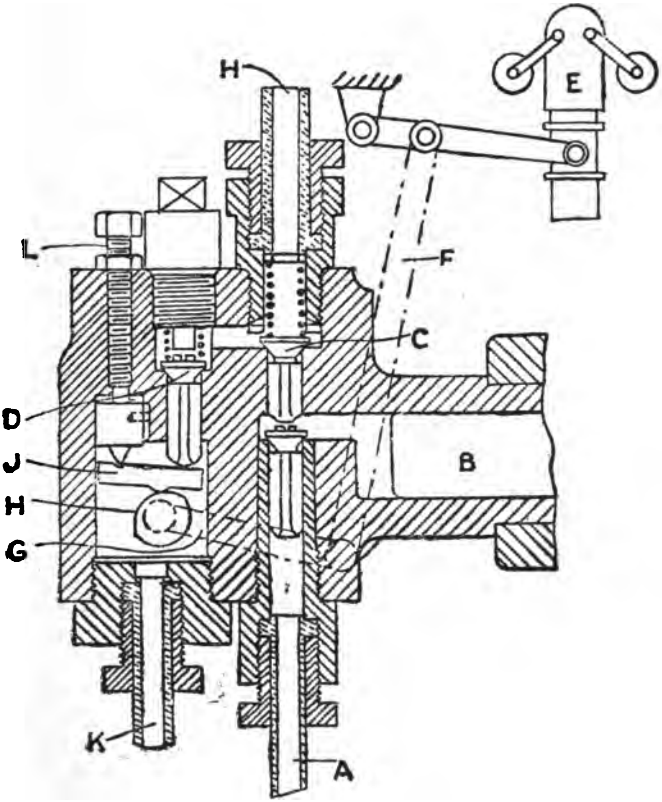


Fig. 70.—Fuel Oil Pump and Governing Gear.

Cross Vertical Four-stroke Engine.—The Cross engine, manufactured by the Westinghouse Brake

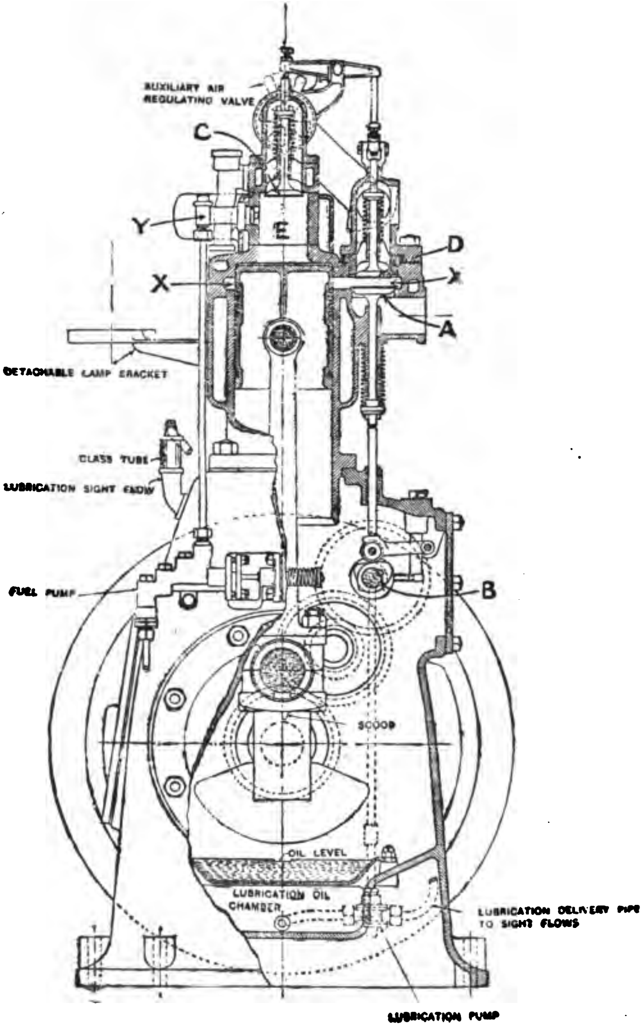


Fig. 71.—Cross Four-stroke Engine.

Company, Ltd., is a four-stroke engine with several interesting features. A section of a 10 H.P. single-cylinder engine is shown in fig. 71. The exhaust valve A is opened directly from the half-time cam shaft B, and the two air inlet valves C, D are also operated from the cam shaft, but through rocking levers.

The air inlet valve C opens directly into the combustion chamber E; the other inlet valve D and the exhaust valve A open into an annular pocket or chamber X, which is cut off by the piston when the latter is in its highest position.

The combustion chamber E is unjacketed, so that it is equivalent to a hot bulb, and thus serves for ignition. The inlet valve C at the top of the combustion chamber is, however, placed on a water-jacketed seating.

The action in the cylinder is as follows:—

Starting.—A small iron bulb (not shown), screwed into the combustion chamber E, is heated by a lamp before the engine is started, and serves to ignite the charge for the first few revolutions.

Suction Stroke.—The downward motion of the piston draws air into the cylinder through the valves C and D.

Compression Stroke.—The upward movement of the piston first compresses the whole of the air in the cylinder. Towards the end of the stroke the annular chamber or pocket X is covered by the piston, and the air thus trapped in the combustion chamber is further compressed to a pressure of about 200 lbs. per square inch.

Working Stroke.—The oil fuel is next sprayed through the injection valve Y into the heated air in the combustion chamber and ignites. The air in the combustion chamber E is only sufficient to burn a small quantity of the fuel. The combustion is thus incomplete until the movement of the piston downwards uncovers the annular chamber X, which contains heated compressed air; and this additional air, mixing with the fuel, completes the combustion during the further movement of the piston. It will thus be seen that combustion is spread over a considerable movement of the piston, and the rise of pressure when the fuel is admitted is not as sudden and as high as usual.

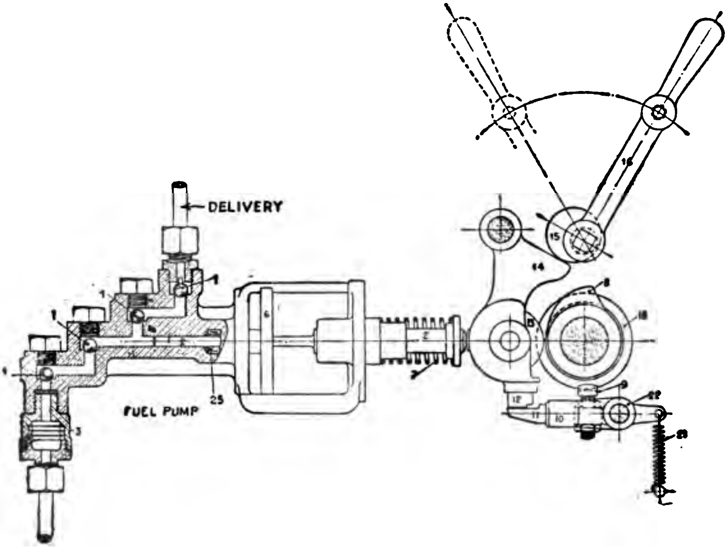


Fig. 72.—Fuel Pump and Actuating Gear.

Exhaust Stroke.—The exhaust valve is opened a little before the end of the power stroke, and the products of combustion are expelled by the upward movement of the piston in the usual way.

The trough lubrication system is similar to that described in Chap. VI. in connection with the Daimler petrol engine. Oil is drawn from the lubrication oil chamber by a pump, and is sent along a delivery pipe to a lubrication sight flow—*e.g.*, a glass through which the flow of the oil can be seen. From the sight flow the oil passes to the trough into which the scoop on the end of the connecting-rod dips.

The fuel pump is also shown in section in fig. 72. It is controlled by the governor so as to give either a long or a short stroke, according to the load; oil is, therefore, always injected, and no power strokes are missed entirely.

Two suction and two delivery ball valves 1 are employed, to ensure that any slight leakage past one valve is checked by the other. The oil is strained by passing it through layers of fine gauze 3 before it is admitted to the pump.

The plunger 2 is moved to the left for the working stroke by means of a cam 8 on the half-speed shaft bearing against a roller 13 carried by a lever 14. The return stroke is brought about by a spring 7.

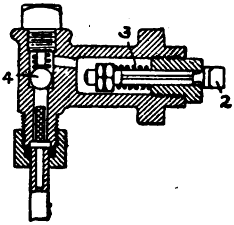


Fig. 73.—Fuel Injection Valve.

When it is necessary to reduce the power of the engine, the forward stroke of the pump is reduced by limiting the return movement of the arm 14. This is effected (1) by the hand lever 16 and eccentric 15, or (2) by the governor raising the arm 10, so that it catches the end 12 of the arm 14.

The next stroke of the cam is thus shorter and the fuel supplied to the cylinder less. When the speed decreases, the governor lowers the arm 10, and the pump plunger is then given a full stroke.

The automatic fuel injection valve Y, which is screwed into the side of the combustion chamber, is shown in section in fig. 73. The valve 2 is kept on to its seat by the pressure in the combustion chamber and by a spring 3. The fuel is forced through by

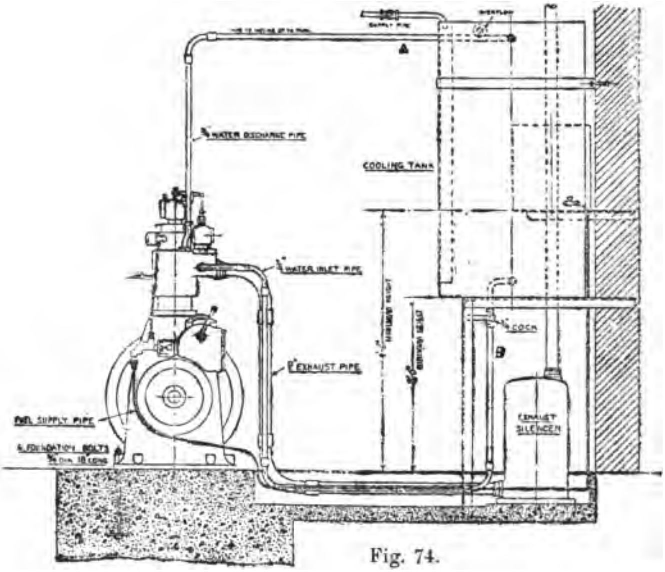


Fig. 74.

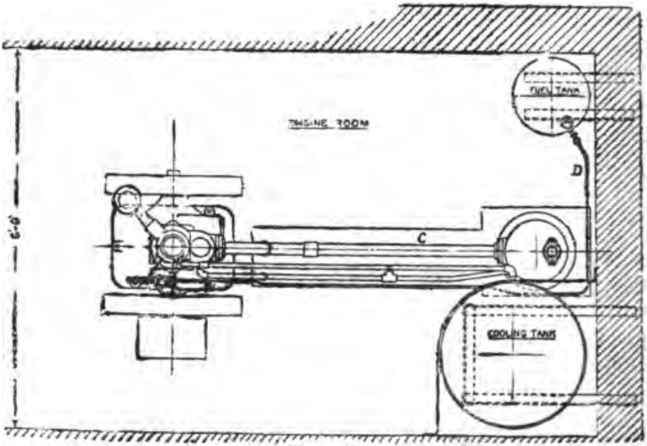


Fig. 75.

Engine-room for Cross Oil Engine.

the fuel pump past the one-way ball valve 4. The pressure then lifts the valve 2, and the oil is sprayed into the cylinder.

General Arrangement of Vertical Engine and Appurtenances.—Figs. 74 and 75 show an elevation and plan of an engine-room in which a Cross engine is installed. The engine is secured by six long bolts to a heavy concrete foundation, and is arranged so that there is plenty of room all round for adjustment and repairs. A large cooling tank is in this case arranged in the corner of the engine-room, the hot water entering the top of the tank by the pipe A, and the cold water leaving the bottom of the tank through the pipe B passing under the floor. The fuel tank is arranged so that the oil feeds by gravity through the pipe D under the floor to the engine feed pump. An exhaust pipe C conducts the products of combustion to an exhaust silencer, from which they are led out of the building.

Blackstone Four-stroke Crude Oil Engine.—Messrs. Blackstone & Co. have recently introduced an engine of the bulb type possessing two specially distinctive features :—

(*a*) The fuel is injected by means of compressed air, as in the Diesel engine, instead of being sprayed into the cylinder by means of a mechanical atomizer, as in most crude oil engines.

(*b*) Only a small portion of the fuel is injected into the hot bulb proper, the greater part being injected directly into the cylinder.

Compressed air injectors for fuel are better than mechanical injectors for effecting atomization or breaking up of the fuel into fine particles, but this advantage is to some extent neutralized by the added complication of an air compressor.

When hot-bulb engines are running light, that is

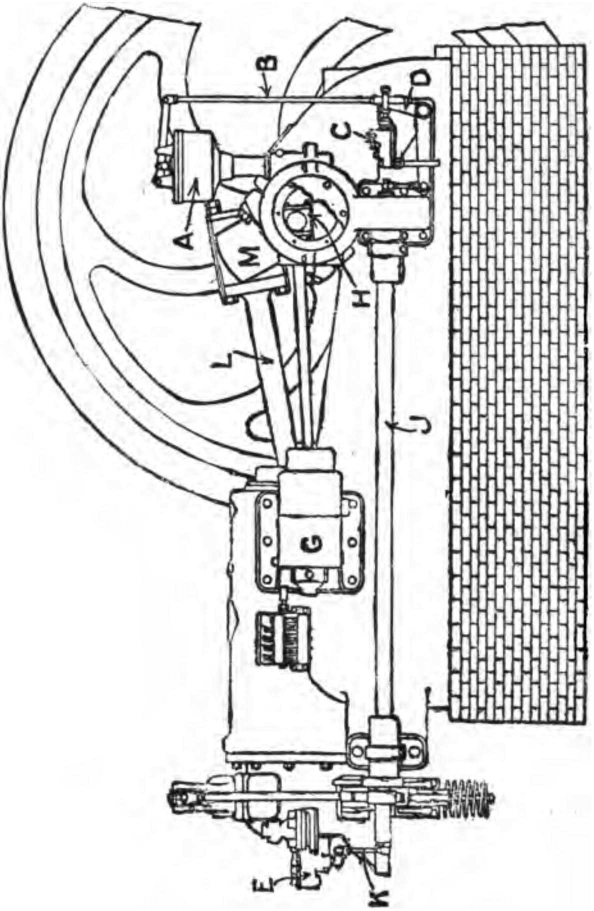


Fig. 76.—Blackstone Four-stroke Engine.

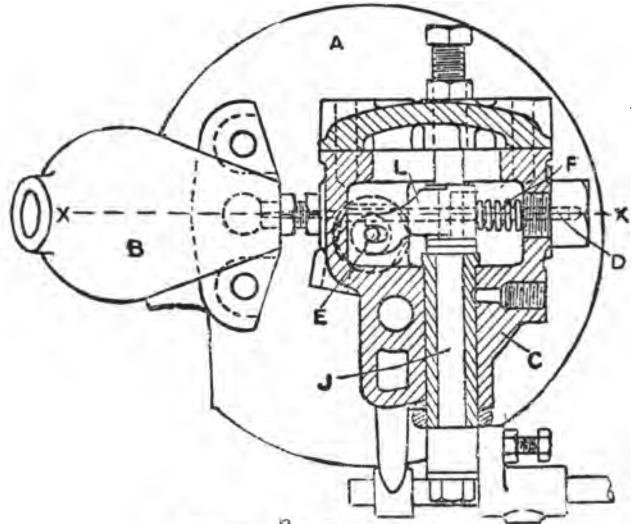
the resistance and the power developed are small, the heat of the burning gases is often insufficient to keep the hot bulb hot enough to ignite the fuel. If the engine has to run long under such conditions, it is necessary to heat the hot bulb from the outside as at starting.

In the Blackstone engine this difficulty is avoided by a dual injection system. A practically constant quantity of fuel is injected into the hot bulb whatever the power developed, the amount of fuel sprayed direct into the cylinder being varied according to requirements. The hot bulb is, therefore, kept hot under all conditions, and no external heating devices are required under light loads.

An external view of the engine is shown in fig. 76. The external part of the cylinder forms part of the bedplate casting in the larger sizes, and the cylinder proper is constituted by a liner, which is supported at the outer end by the breech end or combustion chamber casting. The fuel injection devices and hot bulb are separate from but secured to the end of the combustion chamber, which, in consequence, can be very effectively water-cooled, and thus kept at a constant temperature, the ignition heat being localized. The constructional features so far mentioned are found also in the Ruston crude oil engine described previously.

The main spray is injected centrally in the end of the cylinder, and a small projection in the centre of the piston assists in spreading the fuel. The governor A is driven directly from the crank shaft instead of, as is more usual, the cam shaft, and it is thus not subject to the irregular running produced by the operation of the cams. A rod B from the governor acts on a wedge D, which regulates the stroke of the fuel pump C, and thus controls the supply of fuel to the engine in accordance with requirements, the fuel being led through a pipe to the dual injection devices E at the other end of the engine. A two-stage

Fig. 77.



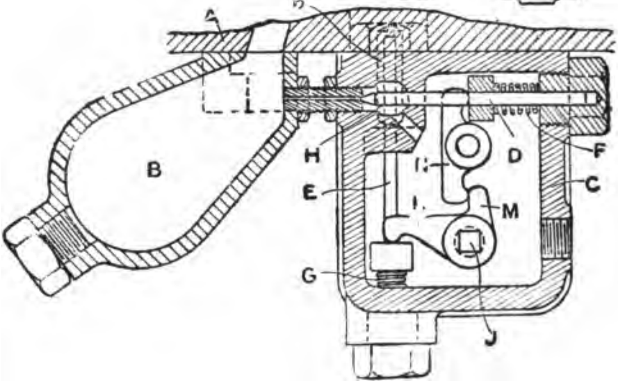


Fig. 78.
Blackstone Dual Fuel Injection.

air compressor G, arranged at the side of the working cylinder, and driven by an eccentric H, is mounted at the side of the engine.

In fig. 77 is shown an elevation partly in section looking at the outer end of the cylinder, and showing the end A of the combustion chamber, the hot bulb B, and the fuel injection box C. In fig. 78 is shown a sectional plan taken on the line X, X of fig. 77.

There are two needle valves D, E, which are operated together, and are normally kept on their seats by springs F, G. The injection box C is kept filled with compressed air at a pressure of about 400 lbs. per square inch, and the fuel is pumped in varying quantities, according to requirements, into an annular space H surrounding the valve D which controls the injection into the hot bulb. The overflow from this space passes to a similar annular space P surrounding the main injection valve E, which is placed at right angles to and slightly below the first-mentioned valve D. At the end of the compression stroke of the engine both valves are lifted slightly, and some air is forced past, carrying the fuel with it. As the pressure of air in the injection box is about 400 lbs. per square inch, and the pressure of air in the cylinder at the end of the compression stroke is only about 150 lbs., there is clearly an ample margin of pressure to ensure the injection of the air and fuel at a very high velocity, the fuel in consequence being very finely divided, intimately mixed with air, and, therefore, tending to burn very completely.

Both valves are simultaneously raised from their seats by a vertical spindle J operated from the cam shaft, and carrying an arm L, which acts directly on the main injection valve E. A tail piece M, on the arm L, acts on one end of a double-armed lever N, the other end of which lifts the valve D. Since the annular fuel space surrounding the end of the hot-

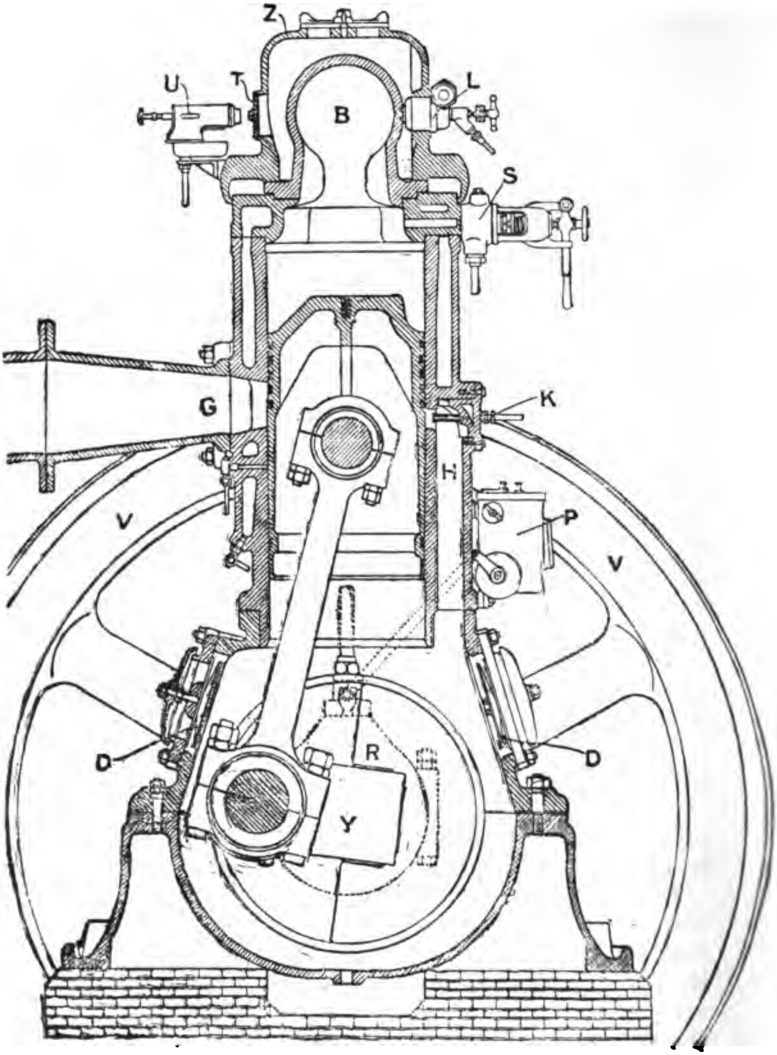


Fig. 79.—Robey Two-stroke Engine.

bulb valve D is always filled first by the fuel pump, it follows that the quantity of fuel entering the bulb is practically the same whatever the load on the engine, and, in consequence, the temperature of the bulb is always sufficient to ignite the fuel. On the other hand, the quantity of fuel admitted through the main fuel valve E varies according to the load on the engine, since it only receives the overflow from the other valve. This, however, is of no consequence, since ignition is always certain.

Robey Crude Oil Vertical Two-stroke Engine.—This engine, shown in section in fig. 79, is of the completely enclosed type, and is made in several sizes developing from 20 to 30 B.H.P.; a smaller size is also made developing from 4 to 20 B.H.P. The cylinder is water-jacketed, but the hot bulb B is provided only with a light cover Z, which tends to prevent radiation of heat.

Fig. 79.

B. Hot Bulb.
D. Automatic Air Valves.
G. Exhaust Port.
H. Transfer Passage.
K. Water-injection Valve.
V. Flywheel.
L. Fuel-injection Valve.
P. Lubricating-oil Pump.
R. Eccentric working Fuel Pump.
S. Compressed Air Starting-valve.
T. Removable Cover for Starting.
U. Starting Lamp.
Y. Crank.
Z. Hot-bulb Cover.

During the up-stroke of the piston the air in the cylinder is compressed into the bulb B, while at the same time air is drawn into the crank case through leather non-return valves D on the sides, this air being used later for combustion.

When the piston has completed its up-stroke, a small quantity of fuel is sprayed into the bulb B through the injection valve L, by means of a pump worked from the crank shaft. The mixture is ignited as usual by the combined effect of the temperature of compression and the heat of the previous explosion. The explosion and subsequent expansion of the gases force the piston down on its working stroke, and the downward movement of the piston compresses the air drawn into the crank case during the previous up-stroke. Shortly before reaching the end of its downward stroke the piston uncovers the exhaust port G, and the burnt gases escape.

After a very small further movement of the piston, the transfer port H is also uncovered by the piston, and the compressed air from the crank case at a pressure of about 8 lbs. per square inch rushes in and assists in driving out the residue of the burnt gas. This scavenging action is rendered more effective by the shape of the top of the piston, which tends to prevent the air from passing out through the exhaust port, and directs it towards the top of the cylinder, a great part of the remainder of the exhaust gases meanwhile escaping through the exhaust port. The fresh charge of air is now compressed on the up-stroke, and the cycle of operations is repeated.

The injection valve L is designed to give a whirling motion to the fuel injected.

Fig. 80 shows an outside view of the top of the cylinder of one of the smaller engines. The fuel pump E is worked by a rod connected to an eccentric R on the crank shaft. The radius of the eccentric is varied by a governor, and the stroke of the pump accordingly varies in the same way, so as to adjust the quantity of fuel injected to the load on the engine.

A lubricating pump P also operated by the eccentric, R, forces oil to the working parts, and it will be observed that the stroke of the lubricating pump depends upon the variable eccentric, and the lubricating oil used, therefore, depends upon the load.

The cooling water is circulated by a pump, which also injects a small quantity of water into the cylinder on each stroke, so as to prevent overheating when working on full load. The water is injected through the nozzle K at the top of the transfer passage H, and is carried in by the air. The amount of water injected is regulated by a small hand wheel W in the smaller engines, and automatically in the larger engines.

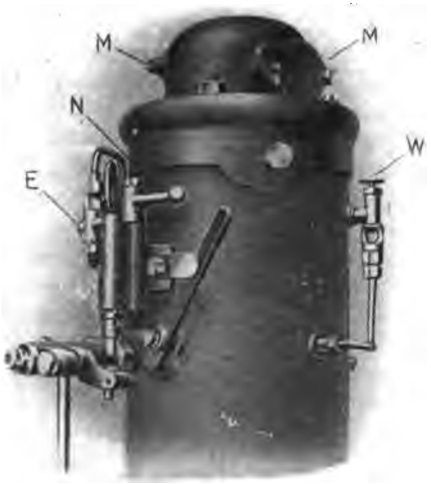


Fig. 80.—Robey Two-stroke Engine.

When starting the small doors T on the side of the hot-bulb cover Z are opened, and the bulb is well heated by a lamp L. The lever N of the fuel pump is then put into the working position, and the flywheel in the case of the smaller engines is swung in a direction opposite to that in which it is intended to turn, when the engine will start working in the proper direction. In the larger engines, the flywheel is turned into a suitable starting position, and compressed air admitted to the cylinder by the valve S turns the crank shaft.

CHAPTER IX.

PRODUCER GAS PLANT.

Gas Production.—Producer gas is generally understood to mean gas obtained by partially burning fuel in a special gas producer. It is distinguished by this partial combustion from coal gas, which is produced in closed retorts heated by an external and entirely independent source of heat, whereas in a gas producer all the heat required is obtained from the fuel from which the gas is obtained. The gas produced consists generally of hydrogen (H), carbon monoxide (CO), hydrocarbons (such as CH_4), carbon dioxide (CO_2), and nitrogen (N), mixed together in various proportion. The last two gases are not combustible, and merely tend to dilute the final product and lower its temperature of combustion.

Practically any kind of fuel containing carbon can be used in gas producers, although some fuels are much more difficult to deal with than others. Anthracite coal and coke are the simplest fuels, and are generally used in small installations, to escape the difficulty which arises when tar is one of the products; but other fuels, such as bituminous coal, peat, sawdust, or waste wood, can be used, generally in specially designed producers.

Water gas is made by passing steam and air alternately through carbon, the alternations taking place at intervals of a few minutes. The air is blown through with the object of maintaining the carbon in a state of incandescence. The principal constituents are hydrogen (H) and carbon monoxide (CO). Its calorific value is about 300 B.Th.U. per cubic foot.

Simple producer gas, or air gas, is obtained by blowing air through a deep bed of coke or other carbon fuel, such as anthracite coal, part of which is incandescent. The fuel is only partially burnt, owing to the supply of air being strictly limited and insufficient for complete combustion. The principal constituent is carbon monoxide (CO) if coke is used, but if the gas is made from coal there is also some hydrogen (H) and methane (CH_4), which give a higher calorific value. About 30 per cent. of the heat of combustion of the fuel is generated in the producer, the remaining 70 per cent. being available for subsequent use. The calorific value is from 70 to 100 B.Th.U. per cubic foot.

Mixed producer gas is intermediate between water gas and simple air gas. A certain proportion of steam is mixed with the air which passes through the incandescent fuel. This gas is sometimes called "Dowson gas," after Mr. J. Emerson Dowson, who has done much to improve the generating plant and to advance its application for power and heating. Many producers for supplying gas engines now work on this principle.

Mond gas, named after its originator, is produced from bituminous coal on a large scale, and in a very economical manner, owing (1) to the means for recovering ammonia, and (2) to the means for utilizing the heat inseparable from any gas producer. The gas consists largely of hydrogen (H) and carbon monoxide (CO), with a small quantity of methane (CH_4). The calorific value is about 150 B.Th.U. per cubic foot. The very low calorific values of gases generated wholly or in part by air are accounted for by the very large proportion of nitrogen in the air supplied. About 50 per cent. of the gas produced in this way consists of nitrogen.

Poor gas is a term applied somewhat vaguely to producer gas, owing to its low calorific value.

Suction gas plants consist of a gas engine combined with a gas producer in such a way that the amount of gas generated depends upon the suction of the engine, so that the gas is generated solely according to requirements. Plants of the suction type are in very common use, and are made in sizes intended to develop from about 5 to 300 horse-power.

Practically every gas engine maker is prepared to supply a suction gas plant for use with his engine.

In most large gas plants the air is forced in under a small pressure.

Chemical Reactions.—We will now consider the principal chemical action taking place in an air gas producer, and some repetition of what has been done in Chap. III. is inevitable. The action of oxygen on carbon is the only question to be dealt with, since the nitrogen, which constitutes roughly four-fifths of the air, is chemically quite inactive.

Carbon forms with oxygen two compounds—carbon dioxide (CO_2) and carbon monoxide (CO). The heat given out by the combustion of one pound of carbon when CO is formed is 4,400 B.Th.U. If CO burns further and form CO_2, a further 10,200 B.Th.U. of heat are generated. The heat given out by the direct combustion of C to form CO_2 is equal to the sum of these two—viz., 14,600 B.Th.U.

Carbon monoxide is formed as the result of the action in a simple air-gas producer, and the further change to carbon dioxide takes place in the cylinder of the engine.

The action in the producer may be represented by the chemical equation—

$$C + O = CO + 4{,}400 \text{ B.Th.U.}$$

Whether this action really occurs directly, as we have assumed it does, or whether there is an intermediate formation of carbon dioxide, is uncertain. It is possible that both actions take place.

In a water-gas producer steam acts upon incandescent carbon, and is, as a result, split up into its two constituents, hydrogen and oxygen. This process requires the application of heat and the action may be represented by the following equation :—

$$H_2O + 62{,}000 \text{ B.Th.U.} = 2H + O.$$

In a mixed producer gas plant both of these actions occur simultaneously, each to such an extent that the heat resulting from one action to a great extent balances the heat required for the other, so that no external heat is required and no cooling is necessary.

National Suction Gas Plant.—This apparatus is designed to use anthracite coal, gas coke, or charcoal, and it consists of two main parts, the first of which is the generator or furnace A, in which the fuel is decomposed, and the second the scrubber B, in which the gas evolved is cooled and cleaned. The general action when the plant is at work will be understood from the following description, and by reference to the sectional diagram (fig. 81) :—

The engine draws its charge of gas from the expansion box 1, which is directly connected with the top of the scrubber by the gas main 2. The scrubber in turn receives its supply of gas from the gas outlet pipe 3, which connects the producer to the scrubber, and this outlet pipe is connected in such a way as to draw off from the producer the gas which is made through the partial combustion of the fuel in the furnace 4 of the producer.

Every time the engine sucks in a charge of gas, the suction action is communicated from the engine through all the interior connections of the gas plant until it is felt right at the furnace of the producer. A definite air inlet 6 is provided to allow the air required for combustion to be drawn into the furnace of the producer at each suction stroke, so as to make

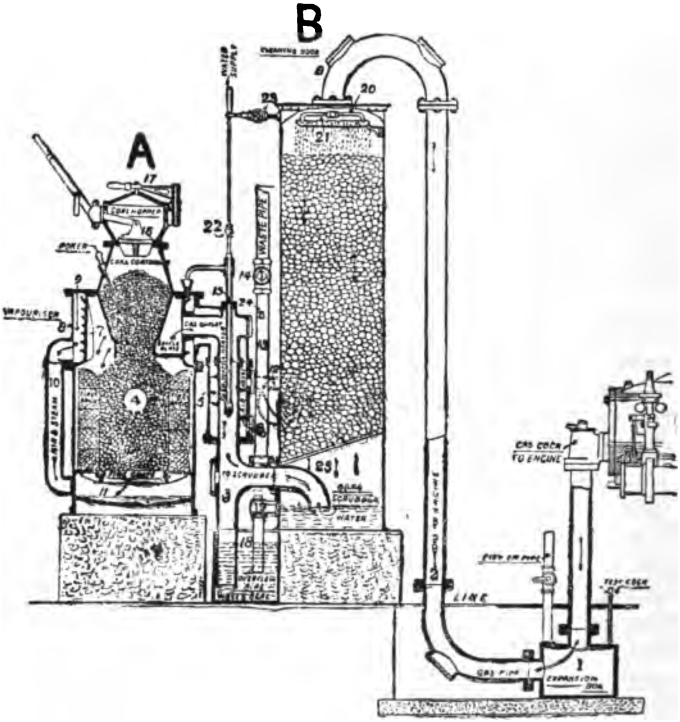


Fig. 81.—National Suction Gas Plant.

additional gas to replace that drawn off by the engine, and consequently the production of gas is quite automatic and in accordance with the demand made by the engine, which in turn is regulated by its governor.

As the gas which comes off at the upper part of the producer is at a considerable temperature, it is used to vaporize the water required for the steam supply. The air and steam supply is arranged as follows :—A jacket 5 is provided round the gas outlet pipe, and, under the suction effect of the engine, air passes in at the inlet 6, and gradually circulating round the gas outlet pipe, is heated considerably before it passes into the vaporizer. The vaporizer is formed by the annular space between the internal circular shell 7 and the external shell 8. The inner shell 7 is heated by the outgoing hot gases coming in contact with its interior, on which heat-catching ribs are cast. On its external surface a supply of heated water is continually fed from the funnel, and is evaporated by the heat of the surface. There is consequently an annulus 9, which is always kept full of steam and hot air while the plant is at work. As soon as the entering air, which has already been heated by its passage through the air jacket 5, reaches the vaporizer it becomes saturated with steam in passing round the vaporizer on its way to the air and steam pipe 10. This latter accordingly feeds the space underneath the grate with a mixture of air and steam, which duly passes through the fire.

There are a few additional important details which are required for working the plant, one of which—namely, the hand-operated fan 12—is used for blowing in air when starting—*i.e.*, before the engine is working. When the fan is being used the blow-off pipe 13 is brought into action by opening the cock 14. This pipe is extended to the outside air, and the cock 14 is shut as soon as the engine starts working. A simple water heating arrangement 15 takes further advantage of the waste heat in the outcoming gas from the producer by heating the water before it enters the vaporizer 9. The device resembles a "Field" tube; the supply

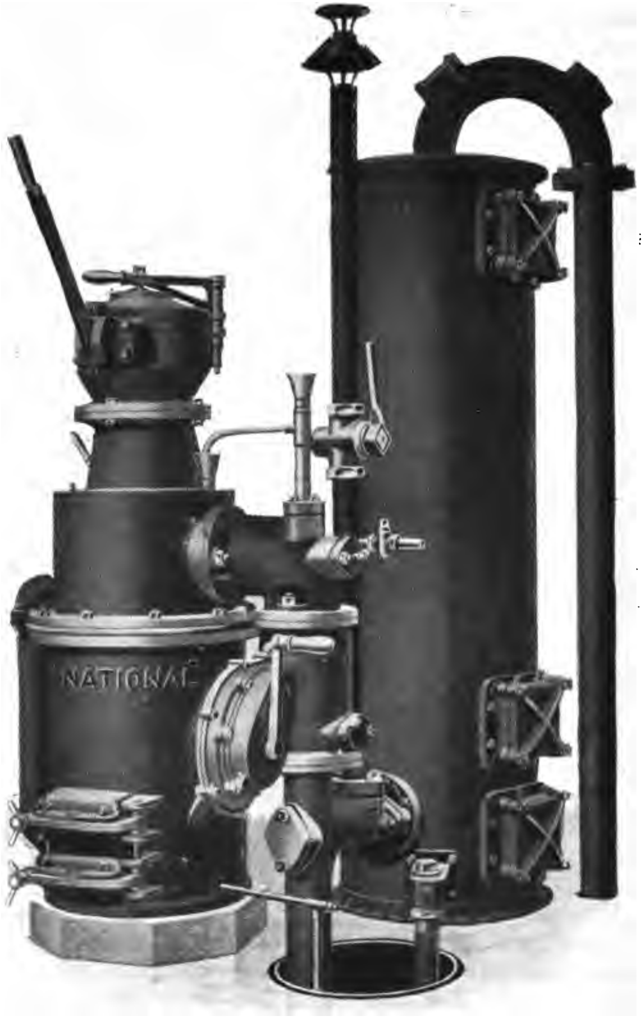


Fig. 82.—National Suction Gas Plant.

pipe projects downwards nearly to the closed bottom end of an outer tube depending into the gas passage, and the water rises between the inner and outer tubes before passing to the vaporizer.

It is essential that no air should enter the producer when at work excepting in the appointed way through the air supply pipe 10, and from thence through the fire grate. Double valves 16 and 17 are, therefore, necessary in the coal hopper, through which the coal is introduced to the inside of the producer. Valve 16 is kept closed while the lid valve 17 is open and the fuel is poured into the coal hopper. The lid valve 17 is then replaced and the hopper valve 16 is opened, the fuel consequently dropping through.

In connection with the scrubber, there is a seal pot 18, into which the overflow pipe 19 discharges the waste water from the scrubber, which is continually used whilst the plant is at work for cleaning and cooling the gas. This water is fed into the scrubber by the sprinkler pipe 20, and it is spread over the whole surface of the coke by the distributing dish 21.

An external view of a plant suitable for an engine of 10 H.P. is shown in fig. 82. The various parts described in connection with the sectional view will be readily identified in the external view, and the compactness of the whole plant will be appreciated.

Such a suction gas plant, together with its gas engine, forms a complete unit for converting the energy of the coal into mechanical work. When compared with a steam-engine plant having furnace, flues, boiler, and steam engine, it will be seen to possess various advantages, not the least of which is the ease with which it can be started and stopped.

CHAPTER X.

HUMPHREY EXPLOSION PUMPS.

A RECENT departure of great interest is the invention by Mr. H. A. Humphrey of an internal combustion pump having a high efficiency. A great many of the usual parts of an internal combustion engine and pump are dispensed with, and the system has been utilized in various ways for pumping large quantities of water or other liquid against a small head or pressure, or for dealing with smaller quantities in opposition to high pressures. The pump has also been employed to compress air at either high or low pressures.

Explosion takes place in a vertical chamber or cylinder, which is closed by the top surface of a column of water instead of the usual piston. This column of water oscillates, and the surface thus functions as a piston. The cycle of operations is either a four- or a two-stroke, and the usual cylinder cooling arrangements can be entirely dispensed with.

Four-cycle Pump.—Fig. 83 shows a diagrammatic sectional view of a pump intended to raise water from a supply tank S T to an elevated tank E T. The supply tank is built round the discharge pipe D, and a number of automatic non-return valves V opening inwards are fitted in the pipe wall. The combustion chamber C forms a continuation of the pipe D, and is disposed vertically. In the head of the combustion chamber are arranged an exhaust valve E, an inlet valve A, and a scavenging valve (not shown), all of which open downward. The exhaust valves open by their own weight, and the inlet and scavenging valves are balanced by a light spring, and are opened by the suction in the cylinder. These two valves are interlocked, so that when inlet valve A closes after its open period it locks itself shut and releases the exhaust valve E and the scavenging valve, which will then open automatically when the pressure drops to the atmospheric level at the end of the working stroke or impulse. When valve E closes it locks itself and the scavenging valve shut, and releases valve A which opens as soon as the suction period commences. Consequently, these valves open alternately as suction or exhaust occurs in the chamber. The exhaust valve is arranged at the end of a tube, which projects downwards into the combustion chamber.

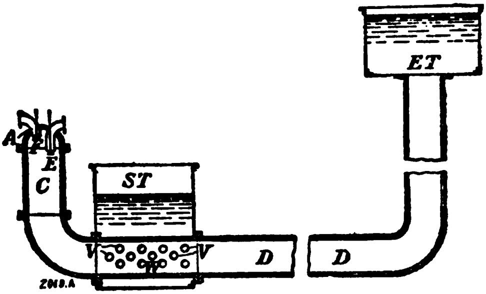


Fig. 83.—Humphrey Four-cycle Pump.

The series of operations taking place may now be considered. Suppose that a charge of air and gas has been compressed into the end of the combustion chamber by the surface of the water, all the valves being closed. At or near the point of maximum compression the mixture is fired by an electric spark, and the resulting pressure forces the water in the pump downwards, and sets the whole column of water in the discharge pipe in motion. By the time that the gases have expanded until their pressure equals atmospheric pressure plus the pressure due to the head of water against which the pump is discharging, the column of water has attained a considerable velocity, and a quantity has been discharged into the elevated tank E T. This is the moment of maximum velocity.

The column of water continues its movement by reason of its inertia, and the pressure in the combustion chamber C consequently tends to fall below that of the atmosphere, so that the exhaust valve E and the water-inlet valves V open. Water entering through the valve V follows the moving column, and also rises in the combustion chamber C. After the moment of maximum velocity, the speed of the column of water decreases, but it still discharges into the elevated tank E T, and, its momentum being exhausted, finally comes to rest. The return movement then starts, and continues with increasing velocity until the water level reaches the exhaust valve and shuts it by impact. A small residue of the exhaust products, together with a quantity of air drawn in through a scavenger valve (not shown) during the outward motion of the water, are thus trapped in the end of the combustion chamber, and form a cushion which checks and stops the moving column of water, and then starts another outward oscillation. When the water level again reaches the exhaust valve the contents of the combustion chamber have fallen to atmospheric pressure, and the inlet valve A then opens; the exhaust valve has previously been locked in the shut position, and cannot open till later. Further movement of the column of water draws in a fresh charge of gas and air. Again the column of water is brought to rest by the pressure or head of water in the elevated tank E T; as soon as it commences to return the inlet valve A closes and the return oscillation compresses the mixture until the ignition point is reached, when the cycle is repeated.

The cycle of operations may be summarised as follows :—

Explosion Stroke.—While the hot gases are expanding to atmospheric pressure, the velocity of the column of water increases, reaches a maximum, and then begins to decrease. The water valves V, exhaust valve E, and scavenging air valve (not shown) open. The column of water gradually comes to rest.

Exhaust Stroke.—The water returns and shuts the exhaust valve by impact, the scavenging valve having been shut previously. Further movement compresses the exhaust gas and air trapped in the head of the combustion chamber.

Suction Stroke.—The pressure of the compressed exhaust gas and air starts another outward oscillation of the column of water until the water level reaches the exhaust valve, when the inlet valve opens and a fresh charge is drawn in.

Compression Stroke.—The return oscillation compresses the fresh charge until the column of water is brought to rest and ignition takes place.

A quantity of water is drawn from the supply tank S T and delivered into the elevated tank E T as the net result of each cycle. The explosion stroke is longer than the suction stroke.

The water column may connect with an air vessel or an elevated stand pipe or tower with open top instead of the elevated tank E T, and may discharge along a pipe or elsewhere. The air vessel or stand pipe then acts as a cushion, and ensures a more or less continuous delivery of water, the action of the pump being unaltered.

Combustion Chamber and Valves of Four-cycle Pump.—The detailed construction of the top of the combustion chamber and valves of a small pump is shown in fig. 84. The exhaust valve E is raised, as mentioned above, by the impact of the surface of the water, and a light non-return valve (not shown) is fitted in the exhaust outlet to prevent any return of exhaust products. The inlet valve A controls the central gas passage and the outer annular air passage. The upper ends of the valve spindles carry

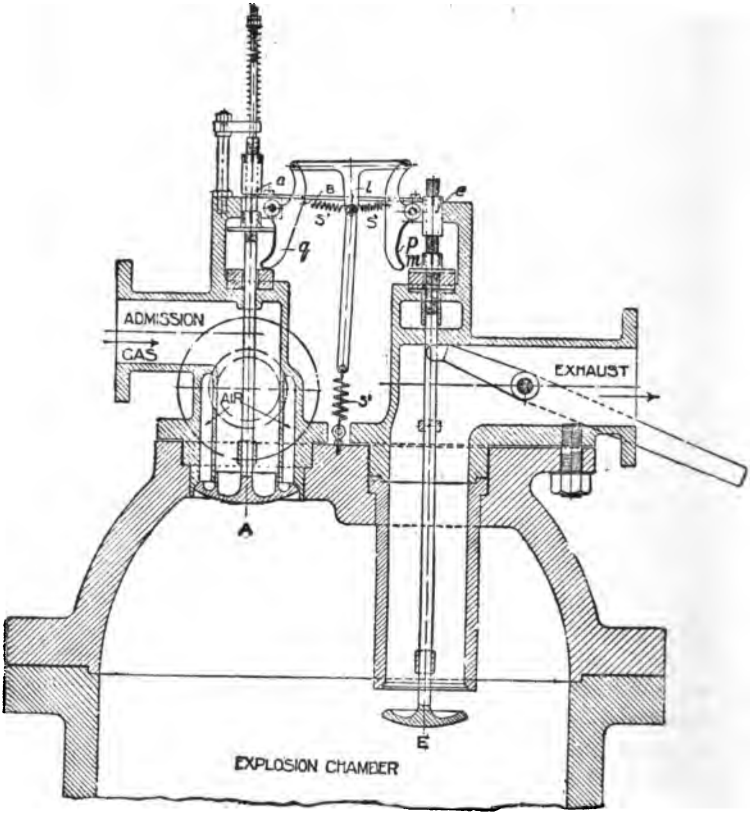


Fig. 84.—Combustion Chamber and Valves of Four-cycle Pump.

collars *e*, and either one or the other of the valves, but not both, is held in its raised position by a locking bolt B slidable horizontally and engaging under one or the other of the collars. The bolt is pressed by springs s^1 s^2 to right or left, according to the position of the arm *l*, to which the springs are attached, and which forms part of a system of links *p*, *q*, *l*.

Consider what takes place when the exhaust valve E is lowered to the open position shown. As the valve spindle moves downwards, a washer *m* engages the curved end of the lever *p*, and throws the links into the position shown, in which the spring s^1 tends to pull the sliding bolt B to the right, but is prevented from doing so by the engagement of the end of the bolt with the collar *e* on the exhaust valve spindle. As soon as the exhaust valve closes, the bolt B springs to the right and engages under the collar *e*, thus locking the exhaust valve in its closed position. The inlet valve is at the same time unlocked, and will be opened the next time suction occurs in the combustion chamber. In a similar way the exhaust valve will be unlocked when the inlet valve closes. The scavenging valve (not shown) is allowed to open at the same time as the exhaust valve. This valve is arranged at the top of the chamber, and admits a layer of air, which remains above the exhaust valve when the exhaust products are expelled, and to a great extent avoids any exhaust residue being left in the combustion chamber. In the larger sizes a number of valves are arranged round the combustion chamber.

Two-cycle Pump.—Fig. 85 shows the head of the combustion chamber for a two-cycle pump, the other parts being similar to those in a four-cycle pump. The inlet valve A is arranged at the top of a tall but narrow part B of the combustion chamber, and a number of exhaust valves E are arranged round the chamber at a lower level.

The cycle of operations will now be considered. Suppose that a charge of air and gas has been compressed into the top B of the combustion chamber and has been ignited. The explosion forces the water in the pump downwards until the water reaches, say, the level *f*, *f* by the time that the gases have expanded to atmospheric pressure. The exhaust and inlet valves then open. The inertia of the water column carries it onwards, and by the time it finally stops the water has reached, say, the level *g*, *g*. During this latter period a charge of air and gas has been drawn in, so as to reach approximately the level *c c* in the narrow part B. On the return movement of the water, the inlet valve closes automatically, and the exhaust gases escape through the valves E until the latter are struck by the water and closed. The water continues its movement and compresses the charge in the chamber B until ignition takes place, and the cycle is repeated.

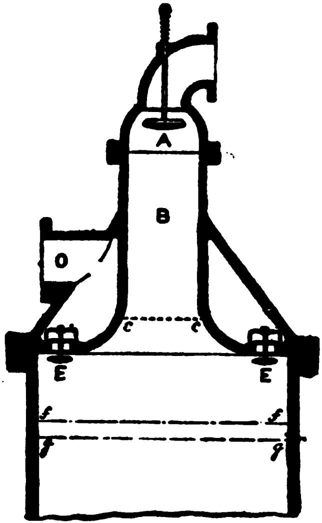


Fig. 85.—Humphrey Two-cycle Pump.

The cycle may be summarised as follows :—

Outward Stroke, first part.—Expansion of hot gases to atmospheric pressure. During this period the velocity of the water column reaches a maximum and then begins to decrease.

> *Outward Stroke, second part.*—Exhaust valves E open by their own weight, and inlet valve A opens by suction. Water column slows up and comes to rest while a fresh charge is drawn into the part B.
>
> *Return Stroke, first part.*—Inlet valve A closed as soon as column of water reverses. The exhaust gases are expelled and exhaust valve E then closed by impact of water.
>
> *Return Stroke, second part.*—The water column by its inertia compresses the charge in the part B, and is thereby brought to rest, after which ignition occurs and the cycle is repeated.

Ignition is effected in all cases by a special device operated when the pressure in the chamber reaches its maximum at the end of the compression period.

Installation at Chingford Reservoirs.—The reservoirs at Chingford for supplying London with water are filled by water which has to be raised from the lower level of the River Lea. In the case of a reservoir completed in 1913, the raising of the water is effected by an installation of Humphrey pumps. One of these pumps is shown in the cross sectional view of the pump-house, Fig. 86. The floor of the house is substantially level with the ground outside, and the pump as a whole is below the ground level. Sluice gates regulate the admission of water from the river to the suction pit below the house. The delivery pipe leads upwards to the reservoir.

The diameter of the combustion chamber is 7 feet, and each pump is capable of delivering at the rate of 50,000,000 gallons per day, the horse-power developed by each being about 250. The head of the combustion chamber contains a large number of valves arranged in three circular rows :—

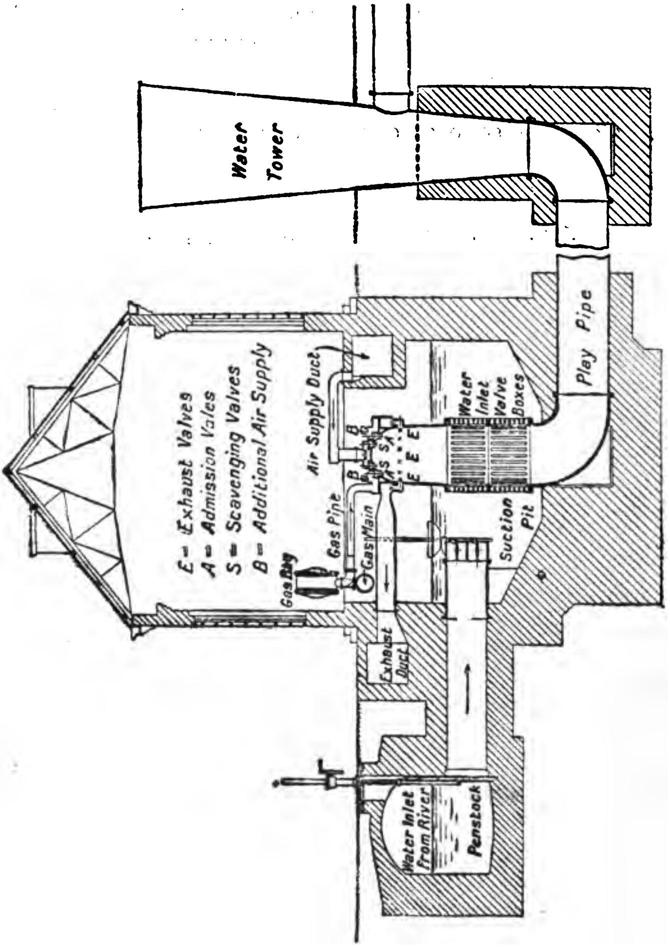


Fig. 86.—Humphrey Pump Installation.

(1) An upper row of eight scavenging valves S.

(2) A second row of eight air and gas admission valves A, arranged in a larger circle and at a slightly lower level than the scavenging valves S.

(3) A lower row of sixteen exhaust valves E, which open into an exhaust belt surrounding the cylinder and communicating with the exhaust duct.

The combustible mixture consists of gas led through the gas main, gas bag and gas pipe, and air admitted through the valves B. The admission valves A and air valves B both communicate with a gas belt encircling the chamber.

The fuel required for operating the pumps is supplied from a Dowson gas plant consisting of four producers, with the associated steam boilers and scrubbers.

CHAPTER XI.

IGNITION.

Introduction.—Engines in which a mixture of air and gaseous or vapourized fuel is admitted to the cylinder must be provided with some independent arrangement for igniting the mixture at the end of the compression stroke. In this category fall gas engines of all kinds, petrol engines, and those oil engines in which a mixture of air and vapourized paraffin is compressed; such an engine, for instance, as the Ruston oil engine described at the beginning of Chapter VIII.

Diesel, hot-bulb, and other injection engines, in which pure air is compressed, do not require provision for independent ignition. The means by which ignition is effected in such engines are described elsewhere.

Electric ignition is now almost universally employed for gas and petrol engines, the only exception being the hot-tube ignition occasionally used for small gas engines as described in Chapter IV.

In the present chapter, then, we will deal in detail with electrical ignition only. Typical examples of battery and magneto ignition will be described, and explanations given of their working. No attempt will be made to explain electrical theory or principles beyond what is considered necessary to give an intelligent understanding of the construction and operation of ignition devices. Anything further is beyond the scope of the book. It is, however, necessary to consider some of the properties of electric currents and magnetic effects, and the relation between the two.

Conductors and Insulators.—Electricity is supposed at the present time to consist of minute positive and negative corpuscles, which hide away among the atoms of which all matter is composed. They are much smaller than the atoms. Their presence cannot be detected unless they are set in motion, and the positive and negative corpuscles thereby separated. In much the same way we do not ordinarily realize the presence of air until it is set in motion and we feel the wind. The electric corpuscles are set in motion by electromagnetic generators or by electric batteries, which bring about a flow or current of electricity either continuously or intermittently.

All substances may be divided as regards their electrical properties into conductors and insulators. All the metals and a few other substances are conductors, silver being the best conductor, and copper coming next. As silver is expensive, copper is in general use for conductors. Carbon is also a conductor, and is used in dynamos and motors. Water is also a good conductor. The non-conducting substances or insulators, such as cotton, glass, porcelain, air or other gas, offer such a great resistance to the flow of electricity that, when it is forced through them by a high electric pressure, it fractures the glass, etc., or burns the cotton, or causes an electric spark in the air or gas. It is such an electric spark which it is desired to produce at the right instant in the cylinder of an engine.

Electric Circuits.—We will now consider a simple electrical circuit. A dynamo A, fig. 87, driven by an engine sends a current of electricity in the direction indicated by the arrow through a resistance such as the wire or filament of an electric lamp B or an electromotor. The voltage or pressure of the current flowing from the dynamo A to the lamp B is greater than the voltage of the current in the return part of the circuit. There is either a continuous or an intermittent flow in a closed circuit.

The electric circuit may be compared with an hydraulic or pneumatic system for transmitting power. In such a system shown diagrammatically in fig. 88, a pump driven by an engine corresponds to the dynamo A. This pump forces air or water under pressure through a pipe *a* to an air or water motor corresponding to the lamp B. The air or water, after imparting energy to and thus turning the motor B, is released at a lower pressure, and returns to feed the pump. Instead of a definite return pipe, the motor B may discharge into a lake or river, and the pump A draw its feed water from the same lake or river, which then serves instead of a return pipe.

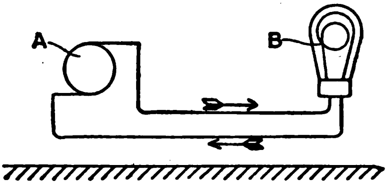


Fig. 87.

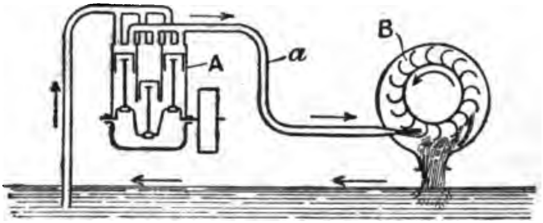


Fig. 88.

The above illustration serves as a useful analogy;

the return wire from the lamp or electromotor to the dynamo may be replaced by an *earth* or *ground* return, as it is called. Such a system is shown diagrammatically in fig. 89. For the sake of illustrating the principle, we may say that the used electricity is discharged from the lamp or electromotor B into the earth, which forms an infinite reservoir of electricity, and the dynamo draws what it needs from the earth. An electric tramway system affords a familiar example. Electric current is led from the dynamos in the generating station through the overhead wires (or underground conduits) to the electromotors on the cars. The electromotors are connected through the wheels to one of the rails, which is in contact with the earth, and the dynamos at the generating station are also connected to the earth.

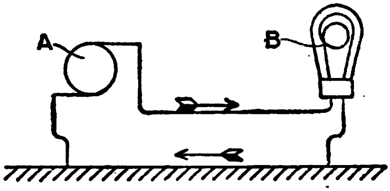


Fig. 89.

In the case of magneto ignition for motor cars, the engine and the frame of the car form the earth return. Both the sparking plug and the magneto are connected to the frame, either directly or through the medium of some other part, such as the engine, the frame thus replacing a special return wire. It is important that the reader should realise that electricity can only flow in a circuit. The current leaving the magneto or dynamo or battery must be conducted back again, and the circulation of the electricity will continue only as long as the magneto or other current producer exerts electrical pressure.

Sparking Plugs and Electric Sparks.—A section through a typical sparking plug is shown in fig. 90. The steel body A is screwed into a valve cap or some other part of the cylinder, so that the points B, C, made of nickel, project into the combustion chamber. The nickel rod D passes centrally through the plug, and is insulated from the steel body A by a non-conducting core E of mica, porcelain, or steatite. The insulating core E is made gas-tight in the steel body A, as it has to stand the explosion pressure in the cylinder. The gaps between the two points B and the point C on the end of the nickel or nickel-steel rod D should not exceed $\frac{1}{30}$ inch; the magneto or other ignition device sends an electric spark across the gap or gaps at the correct instant, and thereby ignites the mixture in the cylinder. The high-tension current is led from the magneto to the screwed terminal J, and thence through the rod D to the point C, and passes across the gap or gaps to the points B, which are connected to the steel body A so that the current returns to the magneto through the engine, etc.—that is, the steel body A is earthed. The insulator E is held gas-tight in the body A by means of asbestos packing H, tightened by a screwed gland G.

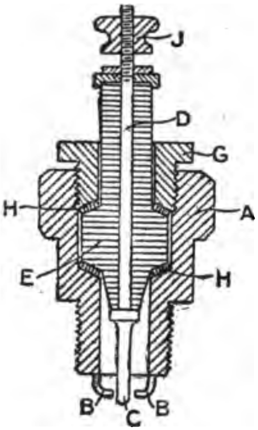


Fig. 90.

The mixture of air and gas or vapour occupying the space between the points of a sparking plug is a non-conductor, and a very great electric pressure is required to force the electricity through such a barrier. When the mixture is at atmospheric pressure an electric pressure of about 2,000 volts is required to force a momentary current of electricity across a gap of $\frac{1}{50}$ inch, and thus give a spark.

But in the interior of the cylinder the explosive mixture, at the end of the compression stroke, may be at a pressure of 90 lbs. per square inch, or about 6 atmospheres, and the electric pressure then required may be as much as 12,000 volts. If the spark gap is greater than $\frac{1}{50}$ inch, the electrical pressure will need to be much higher, or the electricity will be unable to burst through the air and make a spark.

The reference to the volt as the unit of electric pressure will perhaps be made clear by the explanation that measurement of electrical pressure in volts is similar in principle to the measurement of air or water pressure in pounds per square inch or the measurement of length in the unit of 1 foot. The following particulars of electric pressure in ordinary generators will also assist :—

A dry battery gives a pressure of about 1½ volts.
An ordinary cell gives a pressure of about 2 volts.
Town lighting systems supply electricity at pressures of from 80 to 260 volts.
A low-tension magneto supplies current at about 35 volts.
A high-tension magneto gives about 12,000 volts under ordinary working conditions.

A momentary electric pressure sufficient to cause a spark across an air gap may be obtained in two ways :—

(1) *The High-tension Method.*—The current flowing in a primary circuit, independent of the sparking circuit, is suddenly broken, and an induced secondary current at a very high electric pressure is sent through the sparking plug.

(2) *The Low-tension Method.*—In this method the

electric circuit is suddenly broken in the combustion chamber by a small movement given to a lever. The electricity can then only continue to flow in the circuit if it jumps across a small air gap. When the circuit is broken the momentum of the electric current—that is, its tendency to continue in motion—will cause a sufficient momentary difference of pressure on opposite sides of the air gap to give the required spark.

Magnetic Fields and Electric Currents—The Armature.—Iron and steel are the only common substances possessing magnetic properties. But iron differs from steel in that it does not permanently retain its magnetic properties—that is, a piece of iron will cease to be a magnet, and will no longer attract other pieces of iron when the electric current or other magnetizing influence is withdrawn; whereas a piece of steel once magnetized retains its magnetic properties for years.

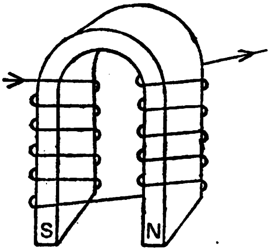


Fig. 91.

Fig. 91 illustrates diagrammatically the method of magnetizing a U-shaped piece of steel or iron. If the material is soft iron—that is, iron fairly free from carbon—the metal will cease to exhibit magnetic properties when the electric current ceases to flow through the coil of wire shown. That is, it is only a temporary or electro-magnet. If, however, a U-shaped piece of steel is subjected to the magnetizing effect of an electric current, the steel will retain its magnetic properties, and thus become a permanent magnet. The capacity for retaining magnetic properties depends upon the composition and the heat treatment of the steel. The magnets used for magnetos are made of special tungsten steel so hardened that a file will make no impression. Such steel is very difficult to magnetize, but, unlike ordinary steel, will retain its magnetic properties almost unimpaired for years, even although subjected to much vibration from the engine.

We will now consider how a piece of steel changes when it is magnetized. The atoms of which it is composed are affected in some subtle way, and careful measurements show that a bar of steel or iron when magnetized becomes slightly longer and a little narrower. But more important than this is the fact that it is capable of attracting (and sometimes repelling) pieces of iron or steel, and that its influence extends into the surrounding space. To illustrate this, the following experiment is frequently performed:—A straight bar magnet N S, fig. 92, is placed on a table and covered with a piece of paper. The paper is then covered evenly with iron filings and gently tapped, when the filings immediately arrange themselves in a series of lines. The lines are called magnetic lines of force, and the space surrounding the magnet is

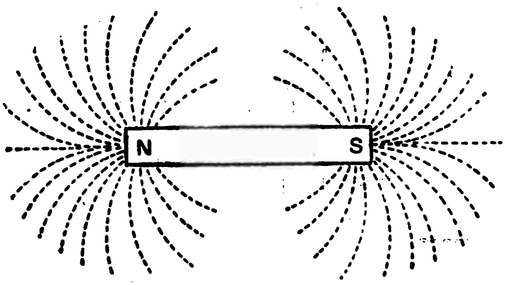


Fig. 92.—Bar Magnet.

known as the magnetic field. It is the effect of these lines of force on adjacent pieces of iron or steel which really accounts for the magnetic properties of the magnet.

Fig. 93 shows the magnetic field of a horse-shoe magnet with soft iron pole pieces as used in a magneto. It may be obtained as described previously in connection with a bar magnet by covering the magnet with a piece of paper, spreading iron filings on this and tapping gently. Most of the lines of force run right round the magnet and traverse the air gap between the pole pieces. They resemble stretched elastic bands in that they continually tend to shorten and resist any effort to lengthen them. This "elastic" property of the lines of force explains the tendency of a magnet to attract (or repel) pieces of iron or other magnets.

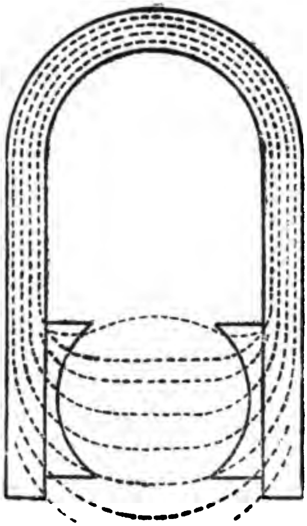


Fig. 93.—Horse-Shoe Magnet.

We have now to consider the manner in which magnetic fields and electric circuits act upon one another so as to produce an electric current for ignition purposes; and we will consider this in connection with the I-shaped armature of a magneto rotating or oscillating between the pole pieces of the usual horse-shoe magnet.

When a conductor forming part of a closed circuit is moved across a magnetic field so that the lines of force are cut by the conductor, an electric current is thereby caused to flow through the circuit. The same effect is produced by a moving magnetic field cutting a conductor. The pressure or quantity of the current so produced depends upon various factors, such as the strength of the magnetic field, the number of turns of wire, the resistance in the circuit, the rate of cutting of the lines of force.

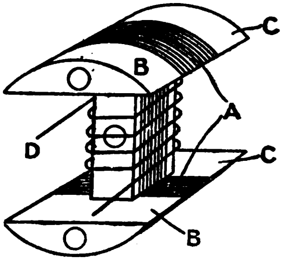


Fig. 94.—Armature Core.

As a preliminary step it will perhaps be well to consider in detail the construction of an armature. A pictorial view of the iron core of a high-tension armature is shown in fig. 94, and a sectional view of the core with the brass end pieces E, F is shown in fig. 95. The core consists of a number of thin iron plates A insulated from one another and bolted together between two solid iron end plates B, C, the whole being so shaped as to leave a channel all the way round to receive the winding D.

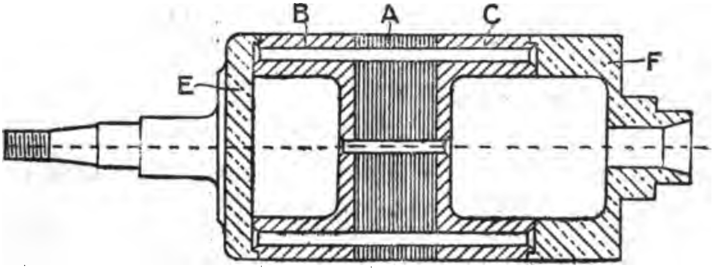


Fig. 95.—Magneto Armature.

When the core has been wound, circular brass end pieces E, F, adapted to run in ball bearings, are secured by screws.

The coil consists of insulated copper wire, each layer being also carefully insulated from those above and below it by layers of silk or enamel, so as to prevent leakage between wires or layers of wire. In a low-tension magneto about 150 turns of comparatively thick wire about $\frac{1}{20}$ inch diameter are employed, and this generates a current of 30 or 40 volts. The modern high-tension magneto has an inner winding of thick wire, and an outer winding of several thousand turns of much finer wire.

When the armature of a magneto is placed in position between the poles of the magnet, as shown in fig. 96, the magnetic field is considerably modified. The lines of force pass through the iron core more readily than they pass through the air. With the armature in the position shown, the lines now penetrate right through the coil.

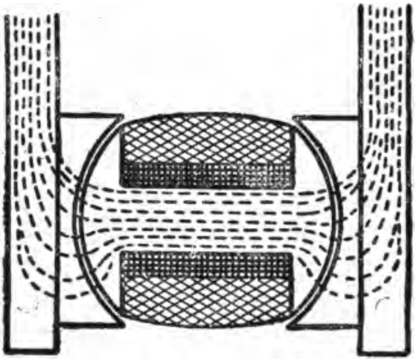


Fig. 96.

When the armature is rotated in a clockwise direction, the lines of force are distorted as shown in fig. 97. As this distortion tends to lengthen them, they exert a kind of elastic resistance, which can be easily felt by turning the armature by hand. Further movement of the armature brings it into the central position shown in fig. 98, in which position it is easier for the lines of force to pass across the ends of the armature core from one pole piece to the other, so that they are now divided and cross by two distinct

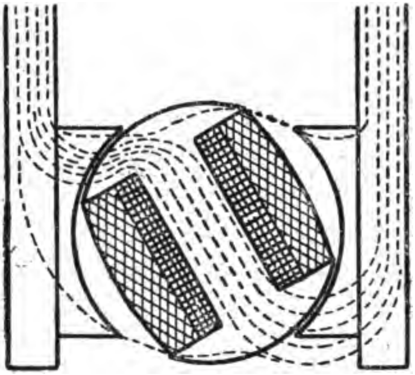


Fig. 97.

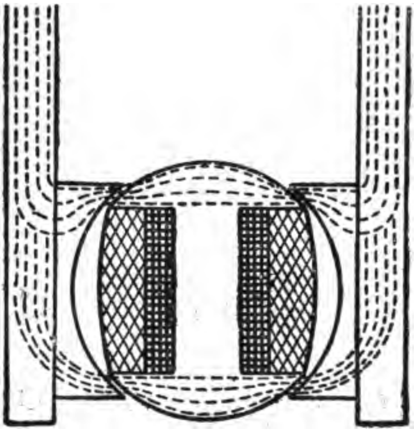


Fig. 98.

paths. The transition from the position shown in fig. 97 to that shown in fig. 98 can only be effected if the lines of force traverse the coils of wire forming the armature winding. In figs. 96 and 97 the lines of force pass right through the middle of the coil; in fig. 98 they pass through the ends of the core and are entirely outside the coil. The crossing of the wires and the lines of force generates a momentary current of electricity in the wires, this current being utilized in any of several ways to obtain the spark in the cylinder.

It is necessary particularly to emphasize the fact that electric current will flow through the wire of the coil only if the wire is moved in such a way that it cuts the magnetic lines of force.

This action is not absolutely instantaneous, but the rise of electric pressure is very rapid slightly before the vertical position shown in fig. 98 is attained, and it is, therefore, necessary so to gear the magneto with respect to the engine that the maximum pressure is obtained at the end of the compression stroke. As the armature core assumes the vertical position twice in each revolution, it is possible to obtain two sparks per revolution, and in multi-cylinder engines the speed of the magneto relatively to that of the crank shaft can be determined accordingly. Thus, in a four-cylinder, four-stroke engine, the magneto runs at the same speed as the crank shaft, while in a six-cylinder engine it is geared to run at one and a-half times the engine speed, as there are then six sparks required in every two revolutions of the engine.

Condensers.—The momentum of an electric current has been referred to previously, and the manner in which the momentum has been utilized to obtain or assist in obtaining a spark in the cylinder has also been mentioned. Under some circumstances, however, it is necessary to absorb the momentum of a current so as to prevent it from jumping across a gap. For instance, when the cam separates the points in the interrupter of a magneto, the momentum of the current urges it across the gap, whereas it is required to stop immediately. To prevent a spark or sparks across the gap, two points on the conductor on opposite sides of the gap are joined to a condenser, which consists in its simplest form of two large sheets of thin metal, usually tinfoil, separated by some insulating material. The condenser functions as a spring; the momentum of the current is temporarily absorbed, so that no sparks occur across the gap. Figs. 99 and 100 show a simple condenser associated with a contact breaker A in a circuit in which current flows as indicated by the arrows. The two tinfoil sheets C, D are separated by an insulator, and are connected to the conductor one on each side of the gap. In fig. 99 the contact breaker is closed and the current is shown flowing steadily, the condenser then being inoperative. When the circuit is opened as shown in fig. 100, the momentum of the current tends to carry it on, and the condenser now comes into operation. The current on the left of the gap flows into sheet C of the condenser, and the pressure rises greatly. The momentum of the current on the right of the gap causes a drop of pressure in the right-hand sheet D below the normal. The

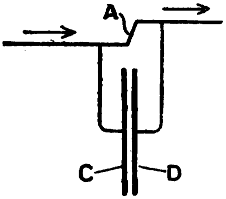


Fig. 99.

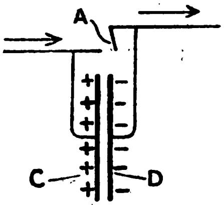


Fig. 100.

plates C and D then have positive and negative charges, and the condenser is represented in its charged condition in fig. 100.

The energy of the current charges the condenser instead of producing a destructive spark across the platinum points of the contact breaker, thus avoiding pitting and rapid wear of the points. The electrical energy is given out again by the discharge of the condenser.

The condenser is used in a magneto and in connection with an ordinary induction coil. It alternately stores up and gives out electrical energy, and thus avoids too great difference of pressure and consequent sparking across the opened points of the contact breaker. The action may be compared to that of the spring buffers in a railway station. If a train runs into fixed buffers its momentum or tendency to continue in motion will result in damage owing to the suddenness of the blow. If, however, it runs into long spring buffers, it compresses the buffers, and is gradually brought to rest, there being no sudden blow.

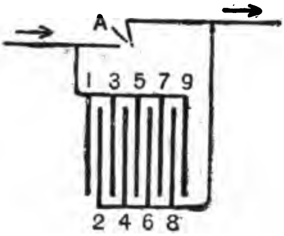


Fig. 101.

In ignition apparatus there is not sufficient room to use two large sheets having the necessary electric capacity, and a number of smaller sheets are, therefore, arranged in the manner indicated diagrammatically in fig. 101. In a magneto a number of circular sheets of tinfoil alternate with thin sheets of mica. The sheets of tinfoil are connected alternately to the circuit on opposite sides of the contact breaker as shown. This construction gives the same effect as the two large sheets described previously.

Induction.—We have now to consider how the stopping or starting of a circuit in a primary circuit induces a current in a secondary circuit as in an induction coil or in the armature of a high-tension magneto. The action is really identical with that occurring in a magneto armature, due to its rotation in a magnetic field—that is, it is really the cutting of lines of force by conductors forming part of an electric circuit—but it is best explained by approaching it from a different point of view. Consider the effect of quickly plunging a bar magnet into the interior of a coil of wire wound on a reel, as shown in fig. 102. The two ends of the coil are connected to a current indicator such as a galvanometer used in physical laboratories. When the magnet is plunged into the coil, the needle of the galvanometer is temporarily deflected, showing that a momentary current is generated in the winding. If the magnet be suddenly withdrawn a reverse momentary current is generated, as shown by the needle swinging in the opposite direction.

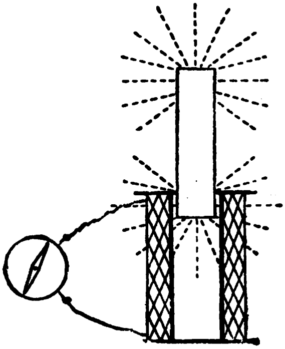


Fig. 102.

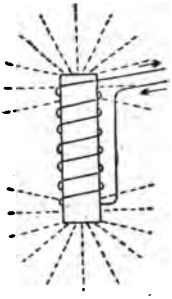


Fig. 103.

The wire of the coil and the lines of force of the magnet cross one another when the magnet is moved in or out, and during this movement of the magnet a current is generated in the circuit. This action is clearly indicated in the figure.

Let the bar magnet be replaced by the electro-magnet shown in fig. 103; that is, a bar of iron having a winding through which a current of electricity flows. As long as the current is flowing, the iron bar possesses the same magnetic properties as a steel bar magnet, but when the current ceases the iron is no longer magnetic. This electro-magnet can then be moved in and out of the coil, and will produce the same current effects as the steel magnet. Suppose now that the iron core with its winding is placed permanently in the coil, as shown diagrammatically in fig. 104. We then have an iron core with a primary winding forming part of the circuit of the battery A and a secondary winding forming part of a circuit B connected to a galvanometer, the two windings being concentric, but entirely independent. If a current is sent through the primary winding by closing the switch S, the iron core is suddenly converted into a magnet. This action is equivalent to moving the magnet suddenly into the interior of the core from a distance, and the generation or induction of a current in the secondary circuit is indicated by the galvanometer. Similarly, when the primary circuit is broken by opening the switch S, and the current ceases to flow, the magnet may be supposed to have been withdrawn suddenly, and a reverse current will be induced in the secondary winding. Such an arrangement forms an induction coil by means of which a momentary current at a high electric pressure is obtained from a battery or accumulator giving a low electric pressure.

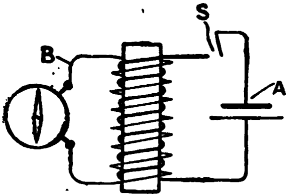


Fig. 104.

The primary winding consists of a number of turns of thick wire, and the secondary consists of a much larger number of turns of fine wire. The relation between the number of coils determines the amount by which the electric pressure of the primary circuit may be increased or diminished. In ignition systems we desire invariably to multiply the comparatively small voltage of an accumulator or low-tension magneto winding many times, so as to obtain a sufficiently high voltage for a spark.

The armature of a high-tension magneto has an inner and outer winding which co-operate in the manner described, so as to obtain a high electric pressure. There are other actions occurring, however, and these will be considered later.

The Trembler Induction Coil.—The principle outlined in the preceding section underlies the action of the induction coil as used in accumulator ignition systems and in some forms of magneto ignition. In the upper part of fig. 105 is shown a diagrammatic view of an induction coil, comprising (1) a core A or bundle of soft iron wires, (2) a primary winding consisting of about three layers of insulated copper wire about $\frac{1}{20}$ inch diameter, (3) a secondary winding of very fine wire containing 12,000 to 15,000 turns, (4) a condenser, and (5) an automatic make-and-break device or trembler arranged in the primary circuit. If the battery circuits are connected directly or indirectly to the terminals B, C, current will flow through the primary circuit when the trembler is in a certain position. The trembler is provided with the object of automatically making and breaking the primary circuit very rapidly. The drawing shows one well-known form, which is constructed as follows:—A steel spring arm D is fixed to a metal contact E carried on a block F of vulcanite or similar insulating material.

A platinum point G on the arm D is pressed upwards into contact with a similar platinum point H on the end of an adjustable screw J carried in a bridge piece K fixed to the block F.

When the battery is connected to the terminals B, C, the primary current flows from the terminal B through the bridge piece K, platinum points H, G, spring arm D, contact E, and then through the primary circuit to the contact C. The flow of the current through the primary circuit converts the core A into a magnet, which draws the spring arm D downwards, thus separating the points H, G and breaking the primary circuit. The core A then ceases to attract the arm D, which springs back and again closes the circuit, reconverting the core into a magnet. The primary circuit is alternately closed and broken so rapidly that the individual blows blend into one another, and the trembler gives a continuous buzz. The different actions occurring may be summarized as follows :—

(1) Arm D up and primary circuit closed.
(2) Core A magnetized and pulls arm D down so as to break primary circuit.
(3) Core A thus demagnetized and spring arm D rises and again closes circuit.

The somewhat complex form of the arm D is accounted for by the desirability of obtaining a rapid break. The movable platinum contact G is carried on a light auxiliary spring fixed to the main spring D, and the actual separation of the platinum points is not effected at once. The curved attachment *a* on the main part D moves downward first, and, when it is moving rapidly, it strikes the auxiliary spring and effects the "break." That is, the point G, instead of being merely pulled downwards, as it would be if attached directly to the arm D, is struck downwards by means of a blow from the attachment *a*. The condenser *b* is connected to the primary circuit on opposite sides of the trembler in the usual way, and thus serves as a cushion when the circuit is broken.

At each break of the primary circuit, a current of much higher pressure is induced in the secondary circuit, and is utilized to obtain the spark in the engine cylinder. The condenser ensures that no spark shall occur when the primary circuit is closed, but a stronger spark occurs when it is opened. That is, a spark occurs at " break " but not at " make."

Accumulator and Coil Ignition.—The association of the induction coil with a contact breaker L, distributor M, and battery N, to obtain a spark in each of the cylinders of a four-cylinder engine, is shown diagrammatically in fig. 105. Thick lines indicate the primary circuit, thin lines the secondary circuit, and dotted lines the " earth " return. One of the best and commonest forms of contact make-and-break is shown at L. In this construction a circular aluminium case includes a ring of insulating material in which is embedded flush with the surface a number of steel segments *d* spaced evenly round the circle, the number of segments being equal to the number of cylinders. Each segment is provided with a terminal, and all the terminals are connected to the terminal C of the coil. The central axis *e*, usually the cam shaft, carries round at half engine speed a metal arm *f* having a steel roller on its end. This roller is pressed outwards by a spring and by centrifugal force, and engages the steel segments in turn, thus closing the primary circuit on each occasion for a short but definite period. During each of these periods the trembler " buzzes " and gives a number of induced electrical impulses in the secondary circuit of sufficient pressure to give sparks in the cylinders. In the event of there being more than one cylinder a distributor M is used to send these high-tension currents to the sparking plugs in turn. The distributor is similar in principle to the contact make-and-break (that is, a rotating member engages metal segments embedded flush with the surface of a ring of insulating

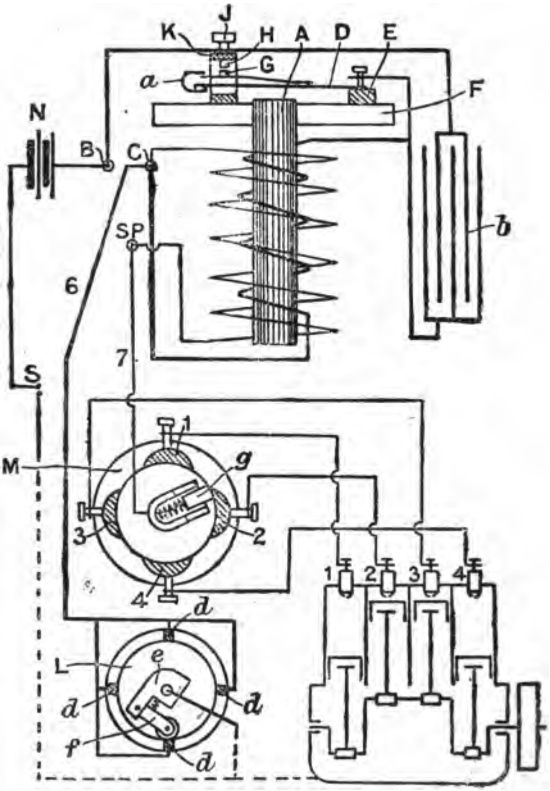


Fig. 105.—Accumulator and Coil Ignition.

material), but the central rotating metal arm usually carries a carbon brush *g* instead of a roller.

The ignition system is put into or out of operation by a switch S. It will be noticed that the centre *e* of the contact make-and-break, the battery and the external parts of the plugs are "earthed"—that is, connected to the engine of framework. The primary and secondary circuits will now be traced out for the case when a spark is required in the second cylinder.

Primary Circuit.—Starting from the battery, the current flows through terminal B, trembler D, contact E, primary coil, terminal C, conductor 6, steel segment *d* in contact breaker, roller on arm *f*, rotating axis *e* to "earth," and then returns through switch S to battery.

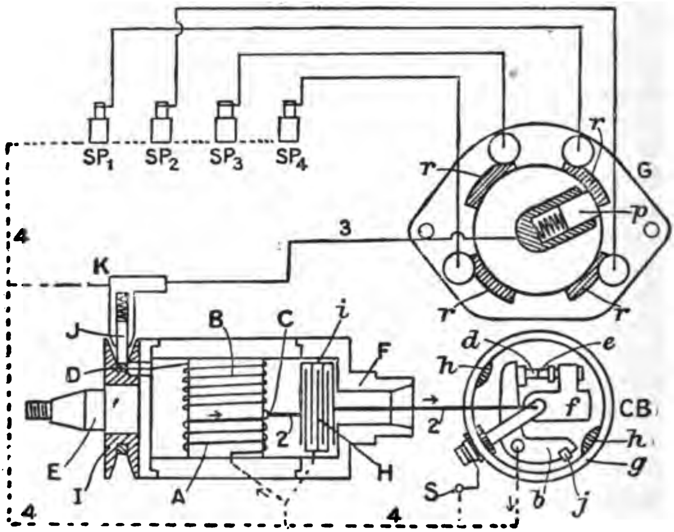
Secondary Circuit.—Starting from the contact C, when the primary circuit is broken, the induced high-tension current flows through the secondary coil, the terminal S P, conductor 7, central rotating part of distributor M, carbon brush *g*, steel segment 2, and sparking plug 2 to "earth," and then returns through the contact breaker L and conductor 6 to the terminal C.

Rotation of the low-tension contact make-and-break and the high-tension distributor at half engine speed bring the sparking plugs successively into action in the order 1, 3, 4, 2 or 1, 2, 4, 3.

High-tension Magneto Ignition.—We will first consider the general method of operation of a magneto for a four-cylinder petrol engine by reference to fig. 106, in which the armature windings, the other parts of the magneto, the sparking plugs, and the various electrical connections are shown diagrammatically. Reference should also be made to fig. 108 in connection with some of the details. The magneto consists of several main parts, as follows :—

(1) The magnets and pole pieces.
(2) The rotor or armature.
(3) The contact breaker.
(4) The distributor.

The armature consists of a core of the special shape described previously wound, firstly, with about 150 turns of copper wire of about $\frac{1}{20}$ inch diameter forming



A. Primary Winding.
B. Secondary Winding.
b. Contact-breaker Lever.
CB. Contact Breaker.
D. Collector Ring.
d, *e*. Platinum Points.
E, F. Armature End Pieces.
f. Insulated Block.
G. Distributor.
g. Contact-breaker Case.
H. Condenser.
h. Non-rotating Segments.
I. Insulator for Collector Ring D.
J. Collector Carbon Brush.
K. Safety Gap.
p. Distributor Carbon Brush.
r. Metal Segments.
S. Switch.
SP$_1$, SP$_2$, SP$_3$, SP$_4$ } Sparking Plugs.
2. Primary Conductor.
3. Secondary Conductor.
4. Earth Connections.

Fig. 106.—Magneto for Four-cylinder Petrol Engine.

the primary winding indicated diagrammatically by A. The secondary winding B consists of several thousand turns of much finer wire on top of the primary winding. The wire is all insulated, and the various layers are further insulated from one another. Brass end-pieces E F run in ball bearings. One end of the primary winding is earthed by connecting it direct to the iron core. The point C, where the primary and secondary windings join one another, is connected to the centre pin of the contact breaker C B by a conductor 2, which passes through the hollow spindle at one end of the armature. The other end of the secondary winding is led to a metal collector ring D carried in an insulating part I. A carbon brush J pressed on to the ring D by a spring carries the high-tension current to the distributor G from which it is conducted to the sparking plug in that one of the four cylinders in which the mixture is fully compressed. A compact condenser H, consisting of a number of circular sheets of tinfoil, is arranged inside the brass end-piece F. One set of condenser plates is connected to the low-tension conductor 2, while the other set of alternate plates is earthed by means of a connection to the end-piece F. The condenser is thus connected to the primary circuit on opposite sides of the contact breaker.

The contact breaker C B runs at the same speed as the armature, and is arranged to break the primary circuit twice in each revolution of the armature. Its construction is as follows:—A bent lever *b* is pivoted at the angle on a pin R carried by the disc on the end of the armature spindle, so that the lever is electrically connected to the armature core, and is thus earthed. The long arm of the bent lever carries a platinum point *d*, which is pressed by a spring into contact with a similar adjustable point *e* carried on a block *f*, insulated from the disc and connected to the conductor 2. The whole of the parts just described rotate with the armature inside a non-rotating circular box or case *g*, on the inside of which are two projecting steel segments or rollers *h*.

Twice in each revolution the projecting plug *j* on the short arm of the bent lever *b* knocks against a segment *h*, and the platinum points are separated sharply, thus breaking the primary circuit. Summarizing, one platinum point *e* is connected to the armature winding and the other point *d* is earthed, so that when the two are separated the current from the primary winding can no longer flow through the contact breaker to earth, and a spark in the cylinder is produced in a way that will shortly be described.

If the magneto is used in a single-cylinder engine, the high-tension wire 3 is connected directly to the sparking plug, but when the magneto has to produce a spark in each of several cylinders, a distributor G (running in the case of a four-cylinder engine at half crank-shaft speed) is employed. In the present case, the high-tension lead 3 is connected in turn to the sparking plugs $S P_1$, $S P_2$, $S P_3$, and $S P_4$ in each of the four cylinders, through the medium of the distributor, which consists of (1) a rotating carbon brush *p* carrying high-pressure or high-tension current from the conductor 3, and (2) a shell of insulating material having a circular interior part in which is embedded four metal segments *r* connected one to each sparking plug. The carbon presses lightly on each metal segment in turn.

The primary circuit consists of—the primary winding A, the conductor 2, the block *f*, platinum points *d*, *e*, lever *b*, pivot of lever, and the earth return 4 to the primary winding A.

The secondary circuit consists of—the secondary winding B, the collector ring D, carbon brush J, conductor 3, carbon *p* of distributor, one of the wires leading to a sparking plug, spark gap, earth return 4, and primary winding A.

The manner in which the magneto produces a spark will now be considered. Just before the points *d*, *e* of the contact breaker are separated, the rotation of the armature between the magnet poles causes a flow of current through the winding A and the complete primary circuit. At the same time there is produced in the secondary winding an electrical pressure, which is insufficient by itself to cause a spark, this effect being due to the turning of the secondary winding in the magnetic field. When the contact breaker opens the primary circuit, some of the current flows into and is temporarily stored up in the condenser, thus preventing sparking across the points *d*, *e*. The breaking of the primary circuit, and the consequent stoppage of the flow of the current in the primary winding, induces a momentary flow in the secondary circuit B, this effect being similar to the induction effect in a coil. These two effects combined result in a momentary electrical pressure of over 10,000 volts in the secondary winding, and this is sufficient to cause a spark across the gap of one of the sparking plugs, so that the current escapes to earth. Earth —that is to say, the engine or frame—forms the return for both the primary and the secondary circuits.

To sum up, the two principal effects which together result in the production momentarily of a very high electric pressure in the secondary circuit are :—

(1) The pressure in the secondary winding due to its movement across the lines of force in the magnetic field.

(2) The induction effect in the secondary circuit due to the check of the flow in the primary circuit.

In the event of the voltage in the secondary circuit becoming excessive, by reason, for instance, of one of the wires leading to a sparking plug becoming disconnected, the current may escape to earth through the safety gap K; that is, the sparking plug is short-circuited. This avoids the risk of an excessive pressure in the secondary circuit breaking down the insulation of the armature winding.

The magneto may be put out of operation by a switch S, which will then connect the block *f* directly to earth, so that the primary current cannot flow through the points *d*, *e*.

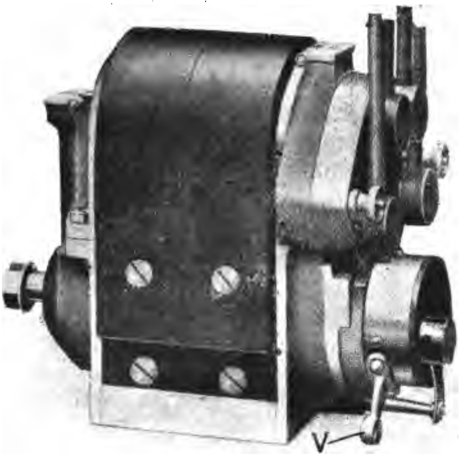
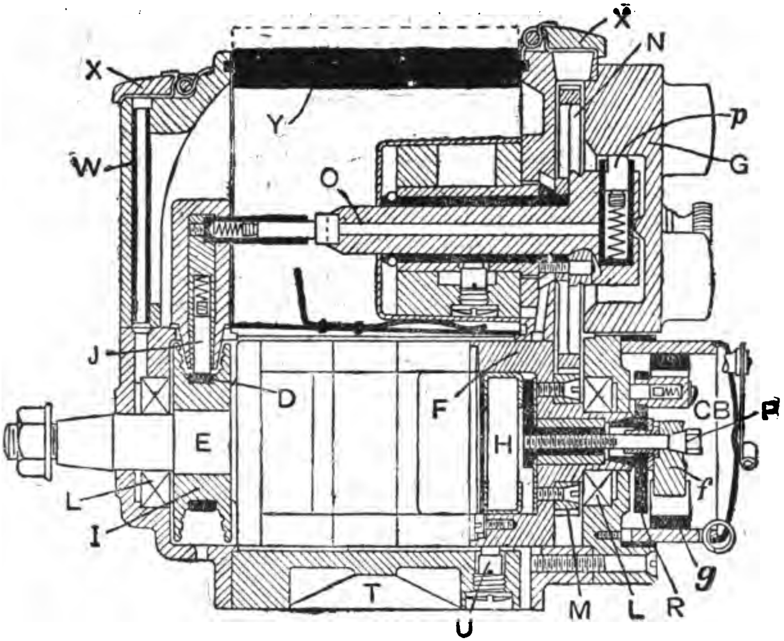


Fig. 107.—Thomson-Bennet Magneto.

The detailed construction of a Thomson-Bennet four-cylinder magneto will now be further described, with special reference to fig. 107, which shows an external view of a dust and damp-proof type, and fig. 108, which shows a section taken on the axis of the armature. The two spindles on the ends of the armature run in ball bearings L, the spindle or end-



CB. Contact Breaker.
D. Collector Ring.
E, F. Armature End-pieces.
***f*.** Insulated Block.
***g*.** Contact-breaker Case.
G. Distributor.
H. Condenser.
I. Insulator for Collector Ring D.
J. Collector Carbon Brush.
L. Ball Bearings.
M, N. Gear Wheels.
O. Distributor Spindle.
P. Contact - breaker Screw Fastening.
***p*.** Distributor Carbon Brush.
R. Disc on Armature Spindle.
T. Magneto Base.
U. Earthing Contact for Armature.
W. Aluminium End Plate.
X. Lubricating Covers.
Y. Magnet.

Fig. 108.—Thomson-Bennet Magneto.

piece E being driven from the engine, and the end-piece F driving the distributor and carrying the rotating parts of the contact breaker. A toothed pinion M, secured by set screws to the end-piece F, gears with a toothed wheel N on the distributor spindle O, so that the distributor is driven at half the speed of the armature. The pin P serves to connect the block *f* electrically with the armature winding, to clamp the block to the disc R, and to hold the disc on the end of the armature spindle. The distributor spindle O rotates in a bearing in an aluminium cover, which completely encloses the end of the magneto. The shell carrying the steel segments of the distributor is secured to the aluminium cover plate by means of two set screws. An aluminium cover plate W also closes the driving end of the magneto.

To ensure constant electrical connection between the armature and the base T for earthing purposes, a carbon contact U in the base is pressed upwards by a spring against the periphery of the brass end-piece F on the armature.

The spark may be advanced or retarded by adjusting the case *g* angularly by means of the arm V, fig. 107. The adjustment of the case alters the position of the steel segments or rollers, so that the primary circuit is broken and the spark consequently occurs when the armature is correspondingly more or less in advance of the dead centre. As the armature is positively geared to the engine, the spark occurs when the crank of any cylinder is more or less ahead of the dead centre according to the varying requirements of the engine. Thus, at high speeds, the spark may be advanced so that it occurs when the crank is perhaps 30° from the dead centre.

High-tension magnetos are frequently combined with accumulator and coil systems on motor cars, the two being used alternatively.

A magneto must be turned fairly quickly, a spark being unobtainable below a certain speed. Some engines are for this reason often difficult to start by hand on the magneto, and an alternative system is then desirable.

Oscillating Magneto.—High-tension oscillating magnetos are often used on gas engines. The magneto is very similar to the high-tension rotating magneto just described, but the armature, instead of being rotated continuously, is oscillated by a trip gear in the manner illustrated in figs. 109 and 110. The spindle of the armature is connected to a tripping arm B, by means of which the armature is displaced from the position shown in fig. 110 to that shown in fig. 109. The tripping arm is actuated by a cam C on the half-speed shaft D, and when the cam releases the arm, springs E return both armature and tripping lever to the central position shown in fig. 110. The electric current generated in the primary circuit by this rapid return movement is interrupted when at its maximum by a contact breaker. A high-tension current is thereby induced in the secondary circuit, and causes a spark across the points of the sparking plug. No distributor is required, the sparking plug being connected directly to the secondary terminal. The figures show a Thomson-Bennet magneto as used on gas engines.

Low-tension Magneto Ignition.—Low-tension magneto systems were at one time used on motor cars, but have been superseded by the high-tension magneto. Oscillating low-tension magnetos are, however, used on many gas engines. The magneto is similar to the high-tension oscillating magneto shown in figs. 109 and 110, but the armature has only one winding, one end of which is earthed through the brass base H,

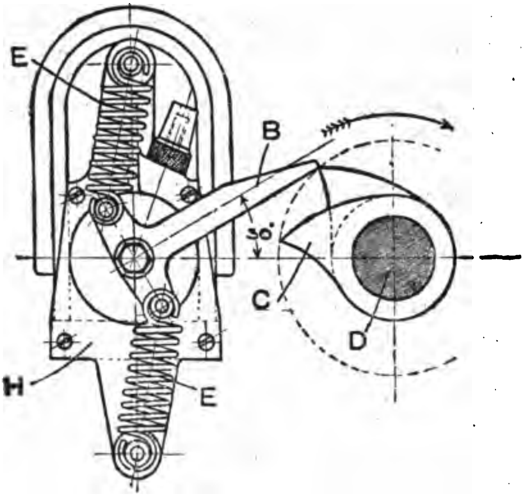


Fig. 109.

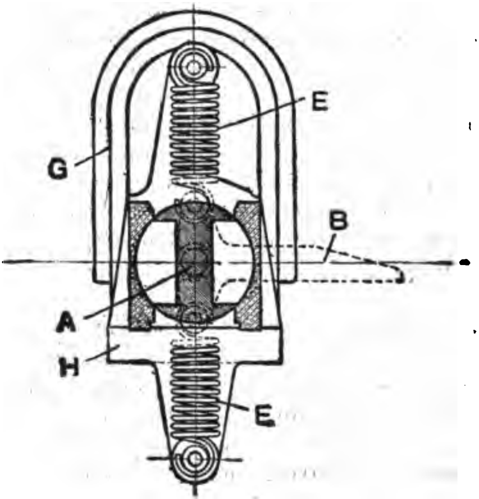


Fig. 110.

High-tension Oscillating Magneto.

while the other end is connected to the contact breaker in the ignition block.

A Crossley low-tension ignition system, as secured to the outside of the combustion chamber of a gas engine, will now be considered in detail.

The system consists of—

(1) The ignition block (fig. 111).
(2) The magneto and its operating mechanism (figs. 112 and 113).

Referring to fig. 111, the current from the magneto is conducted to the outer end of the contact pin D, which is supported in the ignition block C by insulating pieces composed of mica washers. The current then flows along the pin D to the sparking point P, and passes to the contact breaker R, consisting of an arm on the end of a rocking spindle, the outer end of which carries the ignition lever E.

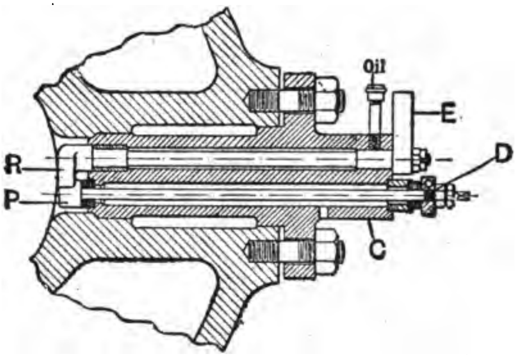


Fig. 111.—Low-tension Ignition Block.

From the contact breaker R, the current flows to the ignition block C, and thence to the engine. When the current is flowing strongly the ignition lever E is suddenly turned so as to separate the contact breaker R and the sparking point P. The inertia of

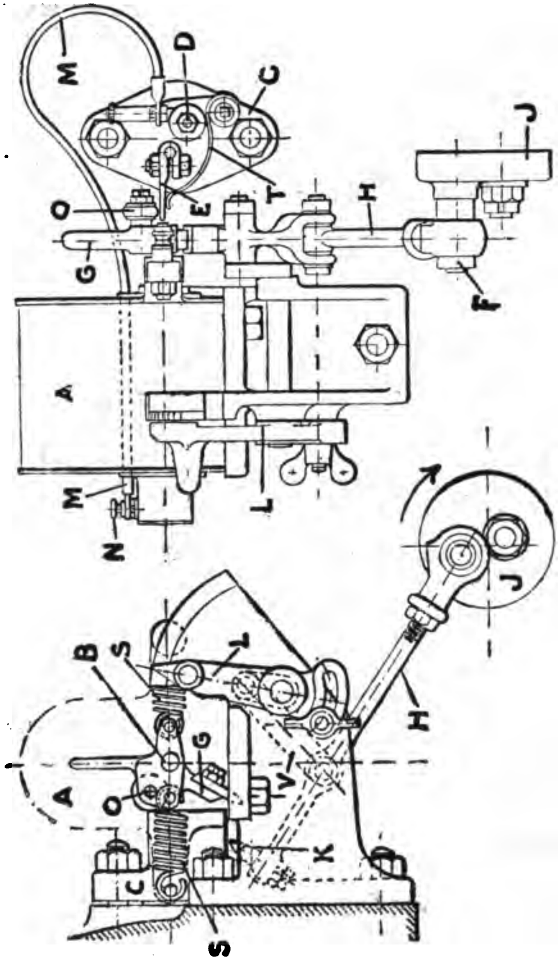


Fig. 112.

Fig. 113.

Low-tension Oscillating Magneto.

the current—that is to say, its tendency to continue to flow—will cause a spark or series of sparks across the gap between the parts R and P, and so ignite the mixture.

The spindle of the contact breaker R should be kept well oiled, to ensure freedom of operation, and it should be allowed a small amount of end play for the same purpose. Care must be taken to see that the insulation of the contact pin D is effective. Moisture, oil, or dirt must not be allowed to accumulate. The drain hole in the lower part of the ignition block C must, therefore, be kept clear, and the parts should occasionally be taken apart and cleaned.

Figs. 112 and 113.

A.	Magneto.
B.	Oscillating Armature.
C.	Ignition Block.
D.	Contact Pin.
E.	Ignition Lever.
F.	Eccentric Pin on Cam-shaft.
G.	Trip Lever.
H.	Pusher Rod.
J.	Disc on Cam-shaft.
K.	Tripping Piece.
L.	Adjustable Ignition Lever.
M.	Insulated Wire.
N.	Magneto Terminal.
P.	Rawhide Striking Roller.
S.	Magneto Springs.
T.	Ignition Lever Spring.

Figs. 112 and 113 show two views of the magneto-operating mechanism and the contact-breaking gear, the whole being mounted on the end of the cylinder and driven from the disc J on the cam-shaft. In this form the armature-returning springs S are arranged horizontally, and the armature is displaced by means of a pusher rod H connected to a crank pin F on the disc J, which rotates in a clockwise direction. The rod H is further constrained by a pivotal connection to a link V, so that the tripping piece K will engage the trip lever G and turn the armature through a small angle in a clockwise direction, the springs effecting the return movement. The time of ignition—that is, the advance or retard of the spark—depends upon the time of release of the trip lever G, and this may be varied by the adjustable ignition lever L, to which the link V is pivoted. As the armature turns rapidly after it has been tripped or released by the trip lever G, a current of electricity is sent along the insulated wire M to the contact pin D in the ignition block C, and when the current is at a maximum the ignition lever E is moved quickly so as to separate the points in the cylinder. This is effected by a raw hide roller O on the oscillating armature striking the ignition lever E at about the end of the return movement of the armature, thus separating the contact breaker R and sparking point P.

In oscillating magnetos, the speed of rotation of the armature at the instant the spark is produced is always the same whatever the speed of the engine, and the spark obtained when starting is therefore as good as that obtained when the engine is running at full speed.

There are many variations and modifications of the ignition systems and apparatus described, but sufficient has been done to explain the principles underlying all ignition systems, and to enable the reader to follow intelligently the construction and operation of other apparatus.

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